Understanding the Relationship Between Livestock Disturbance, The Protocols Used to Measure that Disturbance and Stream Conditions

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UNDERSTANDING THE RELATIONSHIP BETWEEN LIVESTOCK DISTURBANCE, THE PROTOCOLS USED TO MEASURE THAT DISTURBANCE AND STREAM CONDITIONS

by

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ABSTRACT

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by

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Understanding and managing the effects of livestock grazing on stream systems is of particular concern on federal lands throughout the Interior Columbia River Basin. Land managers monitor three short-term indicators of livestock disturbance (streambank alteration, stubble height, and woody browse) seasonally to ensure livestock grazing does not degrade the long-term health of stream and riparian systems. There are multiple methods for evaluating these indicators; one concern is that different monitoring approaches may have different results. In this research I evaluated three short-term disturbance indicators and compared four different protocols for monitoring streambank alteration at the end of the grazing season. In order for these indicators to be meaningful the methods should be repeatable, related to grazing intensity, representative of cumulative impacts throughout the season, and related to long-term stream conditions. Additionally, it is important that land mangers understand how these indicators respond under different climatic and landscape conditions.

In this study I found that the results were dependent on the protocol used and the specific indicator monitored. Measures of streambank alteration and stubble height were moderately repeatable while methods for estimating woody browse were not repeatable. Stubble height and streambank alteration were related to grazing intensity, but the ability to detect alteration at the end of the season was influenced by erosional processes occurring within the grazing season. Streambank alteration was much higher during the drier year of the study because livestock were more dependent of the riparian areas when precipitation was limited. Overall, climatic and geo-physical conditions across the landscape were weakly related to the pattern of disturbance in riparian areas; however, there was higher livestock disturbance in cold arid environments. While the short-term indicators of stubble height and alteration were cumulatively related to long-term stream conditions, the ability to detect changes in individual stream conditions was dependent on the indicator and protocol used. These findings can be used by land managers to make informed decisions about which protocols to use for end-of season disturbance monitoring and will help land managers better understand the relation between short-term indicators and long-term stream conditions.

(106 pages)

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INTRODUCTION

Livestock grazing has occurred on rangelands throughout the western United States since the early 1800's. Historically livestock played an important part in the western economy generating more income than any other single agricultural commodity. Little thought was given to how grazing affected other resources such as fisheries, and native flora or fauna (Platts 1986). As grazing intensity increased, rangelands and adjacent riparian areas deteriorated (Platts 1986). In response, a series of laws and guidelines, beginning with the Taylor Grazing Act of 1934, were established to regulate the number of livestock permitted and to ensure responsible management practices on public lands (Coggins and Lindberg-Johnson 1982). Livestock grazing no longer plays such a dominant role in western economy, but it continues to provide economic stability for ranchers and its legacy carries on as a western tradition.

There is a growing concern about the impacts of livestock grazing in riparian areas (Clary and Kinney 2002). When compared to adjacent uplands, riparian areas are used disportionately by livestock as they seek out forage, water, and shade (Roath and Krueger 1982; Marlow and Pogacnik 1986; Belsky et al. 1999). Changes to channel structure and riparian composition from excessive grazing can lead to degraded functionality of stream systems (Clary and Webster 1989; Platts 1991; Neary and Medina 1996). Trampling of streambanks can cause physical changes in channel morphology through widening of stream channels (Platts 1986; Neary and Medina 1996) and collapse of undercut banks (McIver and McInnis 2007). Soil compaction and shearing of the bank from hooves leads to increased surface runoff, soil erosion, and fine sediments in the streambed (Warren et al. 1986; Usman 1994; Trimble and Mendel 1995). Overgrazing in riparian zones can negatively affect vegetation vigor, community structure, and species composition (Kaufman and Krueger 1984; Bengeyfield and Svoboda 1998). Heavily grazed reaches have lower densities of native species (Fleischner 1994; Frank 2005), decreased tall rhizomatous plant species (Jones et al. 2010), and lower abundance of bank stabilizing hydric plant species (Coles-Ritchie et al. 2007). These disturbed areas favor exotic and invasive inhabitants, and short-lived smaller plants lacking adequate root structure to stabilize banks (Clary and Kruse 2004; Jones et al. 2010). The cumulative effects of increased suspended sediment, excess nutrients, and reduced vegetative cover are detrimental to water quality and instream temperatures (Belsky et al. 1999). In order to maintain healthy riparian zones, federal agencies monitor on the ground conditions in an attempt to ensure that livestock grazing doesn't degrade the long-term functionality of stream channels and riparian ecosystems.

Indicators monitored to assess grazing intensity include stream characteristics such as streambank angle, undercut banks, bank stability, and riparian species composition (Platts et al. 1987; Bauer and Burton 1993; Green and Kauffman 1995; Neary and Medina 1996; Clary 1999; Heitke et al. 2008). The condition of these attributes change slowly over time (Green and Kauffman 1995) therefore are commonly measured when assessing the long-term effects of grazing in riparian areas (McIver and McInnis 2007; Heitke et al. 2008). To maintain the integrity of these long-term attributes and as a measure of accountability, managers also monitor short-term indicators of livestock disturbance.

Short-term indicators such as streambank alteration, stubble height, and levels of woody browse are measured to assess annual livestock grazing disturbance (Heady 1949;

Kauffman et al. 1983a; USDI-BLM 1996; Bengeyfield and Svoboda 1998; Clary and Leininger 2000; Cowley and Burton 2005; Bengeyfield 2006; Heitke et al. 2008; Burton et al. 2011). Streambank alteration is defined by the presence of shearing, trampling, and trailing to the streambank as a direct result from current year ungulate use (Burton et al. 2011; Heike et al. 2008). Stubble height is a measure of the height of residual herbaceous vegetation remaining after grazing (Bengeyfield and Svoboda 1998, Clary and Leininger 2000; Burton et al. 2011). Woody browse is an estimate of utilization to current year branch growth for trees and shrubs (Heady 1949; Burton et al. 2011). Healthy herbaceous and woody vegetation provide strong root systems that stabilize banks and, filter sediment, slow water during high stream flows, and provide shade to streams (Micheli and Kirchner 2002; Burton et al. 2011). The purpose of measuring these attributes (streambank alteration, stubble height, and woody browse) is to estimate how much of the streambank has been disturbed by livestock and other ungulates (Burton et al. 2011). Each of these indicators can be used as a trigger for moving livestock at a predetermined standard level and as an end-of-season indicator of current year grazing intensity (Cowley and Burton 2005; Burton et al. 2011). When these indicators are maintained at a threshold it is thought to facilitate long-term riparian health and can be used to hold land management agencies accountable for riparian management plans (Heitke et al. 2008).

A common method used for measuring the effects of livestock grazing is the Multiple Indicator Monitoring (MIM) protocol described by Burton et al. (2011). This protocol is designed to be a quick and cost effect way to measure short-term disturbance indicators. One concern with using this rapid assessment approach is that it could simplify methods so that they no longer relate to or bias the estimates of the disturbances being evaluated (Anderson 2003; Heitke et al. 2008). For example, when assessing streambank alteration the MIM protocol does not directly measure the area of the streambank that has been altered but instead provides an index of streambank alteration. This index approach can lead to a consistent bias that overestimates the amount of streambank alteration (Heitke et al. 2008). This protocol could therefore become problematic if management thresholds standards were based on more accurate estimates of streambank alteration (e.g., Bengeyfield 2006; Heitke et al. 2008).

Regardless of the measurement protocol, there currently are few rigorous, scientifically reviewed evaluations of streambank alteration standards for grazing (Cowley 2002). The only published article suggests that if streambank alteration is maintained around 17% then bank conditions will improve and cross sectional stream width will be reduced (Bengeyfield 2006). This small scale study consisted of only one protocol and two streams. Based on this paper many management agencies apply compliance standards (e.g., 20%) for an allowable amount of streambank alteration. One concern is that different monitoring approaches may result in different mean estimates of streambank alteration (Heitke et al. 2008). A more rigorous understanding of the applicability of any standard is needed if it is to be broadly applied. Additionally, more information must be considered in order to understand the relationship between different streambank alteration protocol approaches and other short-term indicators of riparian use such as stubble height and woody browse.

Maintaining livestock disturbance at or below the compliance standards is important to land management but can be difficult because of temporal and spatial variation in livestock behavioral patterns. Many studies have looked at factors which influence the annual and spatial distribution of livestock across the landscape (e.g., Roath and Krueger 1982; Senft et al. 1982; Gillian et al. 1984; Marlow and Progacnik 1986; Bailey 2005). Marlow and Progacnik (1986) and Roath and Krueger (1982) found that cattle spent a disproportionate amount of time utilizing vegetation in the riparian zones late in the summer. During years of drought livestock spend a larger proportion of grazing season in riparian zones than under normal precipitation patterns (Marlow and Progacnik 1986). Observational studies have found cattle to spend less time on steep slopes and more time in close proximity to water sources (Roath and Krueger 1982; Gillian et al. 1984). These studies were generally limited to a few pastures and did not quantify characteristics which caused higher use of riparian zones. A large scale evaluation that can incorporate the variability across drainage basins is necessary to better understand conditions which contribute impacts to riparian areas.

In this study I evaluated three short-term indicators of livestock disturbance (streambank alteration, stubble height, and woody browse) and compared four different protocols for monitoring streambank alteration at the end of the grazing season. In order for these indicators to be meaningful, the methods should be accurate, repeatable, related to grazing intensity, representative of cumulative impacts throughout the season, and related to long-term stream conditions. Additionally, it is important that land mangers understand how these indicators respond with different landscape and climatic conditions.

The objectives of this research were to evaluate 1) the relationships and accuracy of four protocols for measuring streambank alteration, 2) the relationships among streambank alteration, stubble height, and woody browse, 3) repeatability of each protocol and indicator, 4) temporal variability of the indicators, 5) the relationship of indicators with landscape and climatic conditions, 6) the relationship between short-term indicators and grazing intensity, and 7) the relationship between short-term indicators and long-term stream conditions. The information presented here can be used by land managers to make informed decisions about which methods to use for end-of season livestock disturbance monitoring and will help land managers better understand the relation between short-term indicators and long-term stream conditions.

METHODS

Study Area and Sample Design

The study area included Forest Service and Bureau of Land Management (BLM) lands within the Interior Columbia River Basin (ICRB; Figure 1). Evaluated reaches were selected from Pacfish/Infish Biological Opinion Effectiveness Monitoring Program (PIBO EMP; Kershner et al. 2004a) monitoring reaches so as to be a spatially balanced sample of Designated Monitoring Areas (DMA) within the ICRB. Designated Monitoring Areas are permanently monumented stream reaches which were selected for monitoring because they contained impacts that result principally from livestock grazing. In addition, eleven reference reaches with no livestock grazing for 30 years or more were selected to serve as controls for this study. The evaluated reaches were located within 17 National Forests (Beaverhead-Deerlodge, Boise, Clearwater, Colville, Deschutes & Ochoco, Helena, Humboldt-Toiyabe, Lolo, Malheur, Nez Perce, Okanogan-Wenatchee, Panhandle, Payette, Salmon-Challis, Sawtooth, Umatilla, Wallowa-Whitman) and four BLM units (Idaho Falls, Prineville, Spokane, and Vale).

The sampled reaches covered a wide range of climatic and geophysical landscape attributes (Table 1). Characteristics ranged from elevations of 155 to 2,360 m, bankfull width from 0.95 to 12.6 m, stream gradient from 0.03 to 6.8%, and sinuosity from 1 to 2.3 (Figure 2). Vegetative conditions at the reaches ranged from meadows, grasslands, coniferous forests, scrublands, open canopy deciduous to barren. Characteristics of the catchment above the evaluated reach ranged from areas of 0.23 to 443.93 km^2, average annual precipitation from 0.31 to 1.68 m, and average annual temperature from -0.08 to 9.84 C°. The large sample size allowed for representation of the variable geographic and climatic conditions of the study area.

To meet the objectives, I implemented a two year study design. Monitoring occurred toward the end of the grazing season from mid September to mid October to accurately capture the cumulative effects of livestock grazing throughout the season. In 2010 a total of 65 reaches were evaluated with 11 reaches serving as reference. In 2011 a total of 147 reaches were evaluated with 10 reaches serving as reference. Sixty-three reaches were evaluated in 2010 and 2011.

Stream Reach Evaluations

Reach setup and sampling methods generally followed directions within the MIM protocol (Burton et al. 2011). The bottom of the evaluated reaches was monumented and observers were provided written direction, coordinates, photographs, and monument locations to ensure evaluations were conducted along the same stream reach. The evaluated reaches extend 110 m upstream from the monumented bottom of the reach. All evaluations occurred along the greenline (Winward 2000). Greenline is the first perennial vegetation that forms a lineal grouping of community types on or near the water's edge and most often occurring at or slightly below the water's edge (Winward 2000). Methods for determining greenline placement were modified from Leary and Ebertowski (2010). Unlike MIM, which allows for plots to be placed 6 meters away from water's edge, this approach uses an upper limit, which is the first flat depositional feature above bankfull. With this method a plot is placed along the streambank even if there is no greenline vegetation (Leary and Ebertowski 2010). This approach was used to insure monitoring corresponded to bank locations where more intensive stream habitat data was collected. Slight modifications of this approach were made to be consistent with the MIM protocol in that the greenline did not extend into the water, did not exceed a 45˚ horizontal angle from level ground, and could be obtained up to a 75˚ vertical angle rotation from the stream parallel (Burton et al. 2011).

Indicators of Livestock Disturbace

I evaluated three short-term indicators of livestock disturbance; streambank alteration, stubble height, and woody browse. Streambank alteration was defined by the presence of shearing, trampling, and trailing of the streambank (Heike et al. 2008; Burton et al. 2011; Table 2). The disturbance had to be obvious and from the current seasons use. "Obvious" streambank alterations, defined by Burton (2011), were those that were readily observed from no closer than approximately 61 cm (2 ft) from the streambank; this meant livestock impacts needed to be evident without kneeling close to or lying on the ground (Burton et al. 2011). Stubble height was defined as the median height of the herbaceous vegetation (graminoids and forbs) along the greenline. Woody browse was an estimate of the percent of current year branches that were grazed by livestock and wild ungulates.

Streambank alteration was evaluated using four protocols 1) the MIM protocol defined by Burton et al. (2011; MIM), 2) a modified version of the MIM protocol (hereafter called Mod) that increased the possible range of values altered by livestock within sampled plot, 3) a Single Line Alteration protocol (hereafter called SLA) implemented by Region 1 of the USDA Forest Service (Region 1 Bank Alteration Task Group 2005), and 4) a line intercept approach (hereafter called LI) modified from Bengeyfield (2006).

Estimates of streambank alteration as determined by MIM, Mod, and SLA protocols, stubble height, and woody browse were rapid assessments using the aid of quadrat frame placed along each streambank. The primary sampling quadrat consisted of two 20 x 50 cm Daubenmire (1959) plots placed side by side (Figure 3) with the 50 cm center bar placed along the greenline (Burton et al. 2011). Observers walked upstream on the left bank and downstream on the right bank, placing the quadrat on the streambank directly in front of the toe every three paces (approximately every 2.75 m). A minimum of 40 quadrat placements were evaluated on each bank. If an observer was approaching the end of a reach and felt they would not obtain the minimum quadrat placement, the pace was then adjusted to that less than 2.75 m so as to obtain at least 40 plots on the streambank. Once the frame was placed on the streambank it was adjusted so the center bar of the frame was along the greenline (Region 1 Bank Alteration Task Group 2005; Burton et al. 2011). All estimates of streambank alteration as determined through MIM, Mod, and SLA protocols, stubble height, and woody browse occurred simultaneously with quadrat placement. This was done as to ensure that all indicator measurements were taken from the same locations.

Streambank Alteration. The MIM protocol for evaluating streambank alteration used a modified five line intercept approach. The sampling frame was divided into five lines extending 20 cm on either side of the greenline perpendicular to the 50 cm center bar (Figure 3). The original frame include bars representing the 1st and 5th lines; the 2nd 3rd, and 4th lines were visually projected by the observer 10 cm apart perpendicular to the center bar representing lines two through four (Burton et al. 2011). For this study I modified the frame to include bars for the three lines that would normally be visually projected by the observer. The amount of alteration at a quadrat frame was recorded as the total number of lines that intercepted hoof alterations, regardless of the amount of the line that was altered. Each line that intercepted alteration was representative of 20% alteration for the 40 x 50 cm quadrat area. The maximum of 100% alteration could be obtained when all five lines intercepted alteration at any point along the bar.

To increase the resolution of the measurement and presumably precision and accuracy, the number of possible intersects of the Mod frame was increased from five to 100 (Figure 3). This was done by dividing each of the five lines into 20 increments; each increment was 2 cm in length. The number of increments that intercepted alteration was record for each of the five bars on the quadrat frame. Each 2-cm increment that intercepted alteration was representative of 1% alteration for the 40 x 50 cm quadrat area. The maximum of 100% alteration could be obtained for a quadrat frame when all 100 increments intercepted alteration.

The SLA method was modified from the USFS Region 1 Bank Alteration Task Group (referred to as point intercept method in the literature; 2005). For this method a 91.4 cm bar was inserted perpendicular to the center bar of the quadrat frame extending 45.7 cm on either side of the greenline (Figure 3). A value of one was recorded for the plot if alteration such as a hoof print intercepted any portion of the 91.4 cm line. This method would normally be performed without the aid of a quadrat frame and the 91.4 cm line would be visually projected by the observer. The number of measurements recorded in this study was lower than the 50 measurements per bank described by the Standardized Protocol for Measuring Bank Alteration on Grazing Allotments protocol implemented through Region One of the USFS (Region 1 Bank Alteration Task Group 2005). The slight deviation of methods was required so as to collect data in a timely manner that was consistent and comparable with the MIM and Mod quadrat placement.

The LI method, modified from Bengeyfield (2006), is a measurement of the linear length of alteration that occurs along the greenline. The LI method is an accurate way of measuring alteration (Kaiser 1983) but takes more time than the other three protocols (Region 1 Bank Alteration Task Group 2005; Burton et al. 2011). With this method measuring tape was placed directly on the greenline for the entire 110 meters on both banks of the evaluated reach. The length of each livestock alteration which occurred directly beneath the tape was recorded (Figure 4).

Estimates of percent streambank alteration were evaluated and summarized for all reaches evaluated in 2010 and 2011 using the MIM and the Mod protocols. Alteration data was evaluated at all reaches using the Mod sampling frame because it permitted both MIM and Mod methods to be collected at the same time. I did this by summarizing alteration by each line within each quadrat placement. In this way if four of the 10 smaller 2-cm increments were altered using the Mod protocol the entire line would be treated altered by the MIM protocol. This permitted the easy conversion of data collected using the Mod method to that of the MIM method. Percent streambank alteration for MIM was determined by summing the total number of lines that had at least one increment of alteration divided by the total number of lines recorded for the reach. Percent streambank alteration for Mod was calculated by summing the total number of increments with alteration then dividing by the total number of increments recorded for a reach.

The SLA method was evaluated at a subset of 30 reaches in 2011. Percent streambank alteration for SLA was computed as the sum of number lines that intercepted alteration divided by the total number of SLA lines evaluated within each reach.

The LI method was evaluated at subset of 12 reaches in 2010 and 15 reaches in 2011. Percent streambank alteration using the LI method was calculated by summing the total alteration divided by the total length summed across both banks (Kaiser 1983). This estimate was likely to be the most accurate in that it is a direct approach rather than an indexed approach (Elzinga et al. 1998).

Stubble Height. Methods for measuring stubble height were adapted from Burton et al. (2011) and the Utilization Studies and Residual Measurements Technical Reference (USDI-BLM 1996). The median height of vegetation was recorded using the same quadrat frame and frame placement as for streambank alteration. Within the frame stubble height was determined in the first subplot section nearest the handle and on the greenline side of the quadrat frame (Figure 5). Height measures were only recorded for herbaceous vegetation (graminoids and forbs) composing at least 25% cover within the 10 x 20 cm portion of the plot used in this measurement. If vegetation didn't cover 25% of the first subplot, the observer then recorded the median height of vegetation in the nearest 10 x 20 cm subplot on the greenline side of the quadrat frame that did have 25% cover. If all four subplots on the greenline side of the quadrat frame were exhaust without encountering suitable vegetation then a value of NA (not applicable) was recorded. Median height was evaluated for all graminoid and forbs within the 10 x 20 cm subplot. This was done by the observer determining the median height of the vegetation within the 10 x 20 cm subplot; this height was measured (by ruler) and recorded. Graminoid or forb was recorded indicating the dominant vegetation type found within the 10 x 20 cm subplot. Mean stubble height was summarized as the total sum of the median stubble height measures and dividing it by total number of applicable measurements recorded for each reach.

Woody Browse. Methods for evaluating woody browse were adapted from Burton et al. (2011) and the Utilization Studies and Residual Measurements Technical Reference (USDI-BLM 1996). Woody browse was the percent class of the current year leaders that had been browsed within a 2 x 2.75 m plot (Table 3, Figure 6). The 2 x 2.75 m plot was projected by the observer and was 2 m wide (1m on each side of the greenline) extending 2.75 m from the quadrat handle to the next consecutive quadrat handle. Woody browse was recorded for each of the following four shrub types: willow (*Salix sp*.), birch and alder (*Betulaceae – Betula sp.* and *Alnus sp.*), dogwood (*Cornus sericea*), aspen and cottonwood (*Populus sp.*). Estimates of browse were evaluated on the first of each shrub type rooted within a plot. The first shrub was defined by that closest to the handle of the quadrat frame. When species of other shrub types were encountered within the plot, no browse class was recorded for those woody shrubs. Percent woody browse was summarized as the mean of the midpoint values for all woody shrub types recorded for a given reach.

Observer Repeatability

Multiple independent evaluations conducted on the same reach at the same time were used to gain an understanding of the repeatability among the observers for each of the livestock disturbance indicators and streambank alteration protocols. Reach evaluations were performed by a total of 33 independent observers over the two year study. Because previous studies have shown that increased training reduces observer variability (Heitke et al. 2008, Olsen et al. 2005, Whitacre et al. 2007, Hannaford et al. 1997) all observers received field training and a written protocol of methods to refer to when questions came up after the training. Field training included how to set up a reach, greenline identification, quadrat placement, identification of ungulate alteration, stubble height measurements, and the different methods for measuring streambank alteration. Additional training provided in 2011 included woody vegetation identification, methods for measuring woody browse, taking repeat photographs, methods for measuring streambank alteration with the SLA method, and practice reach evaluations. Observers were instructed not to discuss the measurements they recorded to ensure independent evaluations.

I selected a subset of reaches for evaluations by multiple observers to capture variability associated with measuring streambank alteration (MIM, Mod, and SLA), stubble height, and woody browse. Repeat evaluations occurred at 24 reaches in 2010 and 48 reaches in 2011. For the repeat evaluations two observers independently measured streambank alteration, stubble height, and woody browse using the modified quadrat frame (there was an exception where one reach was evaluated by four observers in 2010).

At a subset of these reaches, observers also estimated alteration using the LI approach. For the LI method each observer placed a measuring tape along one streambank (i.e., observer 1 placed left bank, observer 2 placed right bank measuring tape) and both observers independently measured streambank alteration along a single fixed LI transect for each streambank. Each measuring tape was secured to the streambanks using turf pins to ensure observers sampled the same transect locations.

Overall this sampling design yielded 72 reaches with repeat observations of streambank alteration for the MIM and Mod methods, 30 reaches with repeat observations for the SLA method, 15 reaches with repeat observations for the LI method, 72 reaches with repeat observations for stubble height, and 38 reaches with repeat observations of woody browse (repeat woody browse data from 3 reaches could not be compared because no shrubs were present; repeat woody browse data from 7 reaches could not be compared because woody browse was recorded by only one observer at the reach).

End-of-Season Variability

The objective of measuring at the end-of-season is to record conditions that are representative of the cumulative effects of livestock grazing throughout the season. One concern was that the amount of measured livestock disturbance could change rapidly post grazing season due to livestock being present, precipitation events, or changes to stream flows. To address this concern a subset of 34 reaches were selected for a second end-of-season evaluation. The average time between the first and second evaluation was approximately 20 days with a range of 10 to 30 days. Disturbances indicators that were evaluated at the secondary evaluations included streambank alteration as determined through MIM and Mod, stubble height, and woody browse. If all livestock had been removed from the allotments then any changes to streambank alteration, stubble height, and woody browse between visits could be attributed to the weathering or wildlife.

Precipitation. Precipitation was quantified for each reach because rainfall could possibly make it difficult to determine whether the disturbance was from the present year or from previous years. Estimates of precipitation were obtained using Snowpack Telemetry (SNOTEL) climate sensor tabular datasets (USDA-NRCS 2012) and Regressions on Independent Slopes Model (PRISM) spatial datasets (PRISM Climate Group 2012). Two daily precipitation records were derived for each reach from the nearest two SNOTEL climate sensors. Each precipitation dataset included the total amount of precipitation (summation of daily precipitation) recorded by the SNOTEL sensor from the date of the first evaluation to the date of the second. The SNOTEL sensors were useful because they were able to provide an estimate of the total amount of precipitation that occurred between the two end-of-season evaluations, but inference to the actual amount of precipitation which occurred at the reaches was limited because the sensors were located several kilometers away (distances of 1 to 45 km) and at different elevations than the evaluated reaches (elevation differences from the reaches to sensors ranging from -338 to 1,139 m). To account for these concerns PRISM monthly precipitation records were obtained for each reach and SNOTEL climate sensor. The monthly precipitation datasets included the sum of precipitation for September and October 2011.

Repeat Photographs. Three to five repeat photographs of streambank conditions and ungulate disturbances were taken at reaches that received two separate end-of-season evaluations. The repeat photographs were visually inspected to determine if there was evidence of change to streambank alteration, stubble height, or woody browse and evidence of precipitation events or changes to the stream stage. For each reach three questions were evaluated: 1) was there visual evidence that livestock were present between the two evaluations (e.g., new hoof prints, browse to vegetation, or new cow patties)?; 2) was there visual evidence that stream stage had increased between evaluations (e.g., risen water levels, new scour lines present, ponding in the adjacent riparian area)?; and 3) was there visual evidence that alteration (hoof prints, shearing, and trailing) had become less evident on the second evaluation? Brief one to three sentence statements were written for each reach indicating and describing any changes that were apparent from the photographs. To prevent any biases, the repeat photographs were assessed independently without knowledge of measured changes in streambank alteration, stubble height, and woody browse. Likewise, the photographs were assessed without any knowledge of the amount of time, precipitation, or changes to stage height which occurred between visits.

Variability between Years

Variation in annual precipitation strongly affects vegetation production and grazing capacity in upland areas ultimately affecting grazing use in riparian areas (Marlow and Pogacnik 1986, Asner et al. 2004; Nippert et al. 2006; Heisler-White et al.

2008). To understand the annual variation of the pattern of livestock disturbance, I evaluate 63 reaches in consecutive years and compared the differences to differences in precipitation. Monthly precipitation was obtained for each reach using PRISM spatial datasets (PRISM Climate Group 2012). The sum of the total amount of precipitation was computed for each water year (1 October through 30 September). Precipitation for the water year was used rather than annual precipitation because the evaluations were conducted in September and October; therefore any precipitation occurring in November and December would have no influences on the measurement taken for the given year. The precipitation that occurs in late October through December accumulates as snow pack ultimately contributing to spring runoff, ground water recharge, subsurface flows, and base flows for the proceeding season.

Landscape Attributes Which May Affect Livestock Impacts

Many stream conditions are affected by a variety of landscape characteristics at different spatial scales (Burnett et al. 2006; Al-Chokhachy et al. 2010). If livestock disturbance were related to landscape conditions one would expect a strong relation among these conditions. Such a finding would suggest consistent difficulty in management of livestock across certain portions of the landscape. In contrast if there were little relationship between landscape characteristics and livestock disturbance then this would suggest past management has had affect on the amount of disturbance to riparian areas. The reaches evaluated in this study covered a wide range of climatic and geophysical landscape conditions that encompassed the variability of many drainage basins within the ICRB (Figure 2). To determine if the disturbance indicators were affected by these conditions, I quantified a set of 11 climatic and landscape attributes

(Table 1). ArcGIS version 9.2 (ESRI 2008) was used to calculate stream density, average precipitation, average temperature, and percent geology within each catchment, and percent of forested vegetation, slope, and road density within a 90-m buffer on both sides of streams from the bottom of each reach and continuing upstream for 1 km (here on after referred to as segment scale). Specifics of methods for deriving each attribute have been reported in Al-Chokhachy et al. (2010).

Grazing Intensity

For any of the disturbance indicators or protocols to be meaningful, results derived from them should be related to grazing intensity. To estimate grazing intensity I placed time lapse cameras at 10 reaches in 2011. The cameras were placed in locations so as to capture as much of the reach as possible while still maintaining a quality photograph in which livestock could be distinguished from wildlife. Each camera was set to take a photograph of the reach once every 15 or 30 minutes during daylight hours (approximately 6 am to 10 pm). The cameras were established and began taking photos in mid June to early July and were removed the second week of October. The cameras were intended to take pictures for three and a half months, but unforeseen events (e.g., cameras knocked over and secure digital cards lost in the field) resulted in large gaps in the photo datasets. Approximately 3,500 photos were taken at each reach (with the exception of one reference reach with approximately 1,500 photos). Over 30,000 photos were visually inspected. Livestock and wild ungulates within the riparian area were documented for each day of photographs. Grazing intensity was determined by summing the total number of days with livestock or wild ungulates within the riparian area and dividing it by the total number of days containing photographs for each reach.

Stream Attributes Which May Be Affected By Livestock Impacts

Livestock disturbance indicators are measured annually because they are thought to cumulatively be indicative of long-term stream conditions (Burton et al. 2011). For this investigation I selected eight stream habitat attributes that were likely to be altered over the long-term by livestock grazing. The selected attributes have been shown to be affected by land management activities such as livestock grazing (Kauffman et al. 1983b; Platts and Nelson 1985; Myers and Swanson 1995; Knapp and Matthews 1996; Clary 1999; Clary et al. 2002; Ranganath et al. 2009) and are considered important physical habitat for native fisheries in headwater streams (Al-Chokhachy et al. 2010). The attributes were sampled according to Heitke et al. (2010) and include width to depth ratio, bank angle, percent undercut banks, bank stability, residual pool depth, percent pools, percent fine sediment (< 6 mm), and median particle size (d_{50}). Specifics of field methods and summaries for each stream habitat attribute have been reported Al-Chokhachy et al. (2010). Data for these attributes were collected by PIBO-EMP as part of a long-term monitoring project and did not occur at the same time or necessarily the same year as the reach evaluations for this study. To reflect current conditions I used the most recent assessments of these attributes for this study.

DATA ANALYSIS

The analysis focused on five different aspects of evaluating the short-term livestock disturbance indicators. The first focused on among and within comparison of the three different short-term indicators as well as the four different protocols for streambank alteration. I then compared the variability of each of the methods evaluated, and the variability of the indicators within and among grazing seasons. The disturbances indicators were then related to climatic and landscape characteristics to determine if there was an effect. Then I related the indicators of livestock disturbance to grazing intensity within the riparian area. Finally, I related these short-term livestock disturbance indicators to long-term indicators of stream conditions. All statistical analysis was conducted using SAS (Version 9.3; SAS Institute 2010) and a significant result was defined as $\alpha < 0.1$.

Indicators of Livestock Disturbace

I evaluated the relationships among the four streambank alteration protocols, MIM, Mod, SLA, and LI. Then I related each of the four protocols to measurements of stubble height and woody browse. For reaches with multiple observations within a year, mean values for streambank alteration, stubble height, and woody browse were computed and used in this analysis. Mean values of the indicators from the secondary observations (to assess end-of season variability in 2011) were omitted for relations with SLA and LI as these methods were not evaluated at the post grazing season evaluations.

Relationship among Streambank Alteration Protocols. I tested whether measures from the four alteration protocols were related to each other. Streambank alteration, regardless of protocol, should be 0% when there is no alteration and should not exceed 100% regardless of level of alteration. The shape of the relationship between these two known points, however, can vary depending upon how the protocol evaluates alteration. I determined which of four models best explained the relationships between the protocols. The simplest model was a linear model with an intercept forced through 0, given by (equation 1):

$$y = ax \quad [1]$$

where *y* is one of the alteration measurements and *a* is the slope estimate of the compared alteration measurement (*x*). Next I evaluated three non-linear asymptotic functions; the Michealis-Menten function given by Equation 2, a 3-parameter exponential function given by Equation 3, and a 2-parameter asymptotic exponential function (Equation 4; Crawley 2007):

$$y = \frac{ax}{(1 + bx)} \quad [2]$$

$$y = a - be^{-CX} \quad [3]$$

$$y = a(1 - e^{-bx}) \quad [4]$$

where *x* is one of the alteration measures, *y* is the other alteration measure and the *a, b,* and *c* parameters control the shape and a asymptote of the relationship. The advantage of these functions is they are non-linear, have an *x y* intercept near zero and should asymptote at values near 100. The fit of these models were compared using Akaike Information Criterion (AIC) with the best model having the lowest AIC value (Akaike 1974). For simplicity and consistency in explanation the independent variable (*x*) was the protocol with the lower increment of measure (i.e., higher resolution of measure). The dependent variable (*y*) was that with the higher increment of measure (i.e., lower resolution of measure). The goodness of fit of the non-linear models was calculated as one minus the ratio between the corrected sum of squares (SSE) and the total sum of squares given by Equation 5:

$$psuedo\ r^2 = 1 - \frac{\mathrm{SSE}}{\mathrm{SST}} \quad [5]$$

Relationship among Measures of Streambank Alteration, Stubble Height, and Woody Browse. Measures of streambank alteration (MIM, Mod, SLA, and LI) were compared with measures of stubble height and woody browse to determine if there were relationships among the short-term indicators. The primary goal of this analysis was to determine if the vegetation and alteration relations had a threshold point in which the conditions of one indicator began to rapidly deteriorate or improve with changes to the another indicator. Likewise, I compared stubble height and woody browse to determine if there was a relation and if there was a threshold value in which conditions began to degrade or improve. The relations were analyzed using a non-parametric method for estimating locally weighted regression lines (LOESS) with a first degree polynomial. Although the use of LOESS does not result in an equation describing the pattern, it does permit visual assessment of the relationships. Stubble height and woody browse were the independent variables when compared to streambank alteration. Stubble height was also the independent when compared to woody browse. Optimal smoothing parameters for the LOESS fit were selected using minimum AIC selection. Additional smoothing parameters were inspected to see if thresholds could be identified through abrupt changes to the slope of the locally weighted regression lines. The AIC selected smoothing parameters were used when the alternative smoothing parameters provided no visual improvement in the identification of a threshold for the LOESS regressions.

Observer Repeatability

The reaches that were evaluated by multiple observers on the same day were used to describe the variability associated with the four streambank alteration protocols (MIM, Mod, SLA, and LI), stubble height, and woody browse. Variability was assessed by calculating the root mean square error (RMSE), coefficient of variation (CV), and signal to noise ratio (S:N) of each disturbance indicator (Kaufmann et al. 1999; Heitke et al. 2008; Roper et al. 2010). The RMSE is the equivalent to the standard deviation of the repeat measurements across all stream reaches and the CV is a dimensionless measure of variability scaled to the grand mean across all reaches (CV = (RMSE/mean) x 100). The lower the RMSE and CV for a given disturbance indicator the lower the variability and the more precise the measurement (Kaufmann et al. 1999; Roper et al. 2010). The advantage of RMSE is that the units are the same as those that were measured. This can be easily used to inform the decision maker of the variability around a standard. The advantage of CV is that there are no units so is it can be compared across different methods. A CV below 30 indicates the method is generally repeatable.

The RMSE and CV were calculated for each disturbance indicator using analysis of variance (ANOVA) techniques. All evaluations were based on current conditions therefore streams that were evaluated by two or more observers in separate years were treated as separate reaches. Linear mixed models (PROC MIXED), with each reach treated as a random effect, were used to decompose the variance among the reaches (signal [S]) to the variance among observers (noise [N]); all error not due to the main effect of stream reach was treated as observer variability; Roper et al. 2002; Roper et al. 2010). The S:N ratio was calculated as the variance among the reaches divided by the variance among observers. A high S:N (> 6.5) indicates differences between reach evaluations were a result of differences to riparian conditions rather than observer variability within the reach (Stoddard et al. 2008). A S:N ratio of one indicates the variability in the disturbance indicator among a set of reaches is equal to the variability among observers in the evaluation of the disturbance indicator for those reaches. Disturbance indicators with a S:N ratio less than 2.5 were considered nonrepeatable, S:N ranging from 2.5 to 6.5 were considered to have moderate repeatability, and S:N greater than 6.5 were considered to have high repeatability (Stoddard et al. 2008; Al-Chokhachy et al. 2010; Roper et al. 2010).

The RMSE, CV, and S:N were used to compare the repeatability of each disturbance indicator as well as provide estimates of the repeatability among the four streambank alteration protocols. Comparisons of CV are appropriate for metrics in different measurement units but can be misleading if local or regional means of the disturbance indicator differ (Kaufmann et al. 1999; Roper et al. 2010). The RMSE avoids such problems by expressing the precision as equal, therefore is more appropriate for comparing variability of metrics applied across many different reaches (e.g., streambank alteration; Kaufmann et al. 1999). One caveat with RMSE is that it may be difficult to make a comparison when units or the scale differ among the attributes.

End-of-Season Variability

The reaches with two end-of season evaluations conducted at different times were used to determine if post grazing season measures of livestock disturbance differed from measures taken toward the end of the grazing season, and to determine if those differences were an effect of continued grazing or weathering events (time, precipitation, and stream flows). Changes to livestock disturbances were computed for each reach as the difference of the two evaluations, where mean disturbances measures from the first evaluation were subtracted from those of the second evaluation. A positive value would indicate an increase of the disturbance indicator measured and a negative value would indicate a decrease of the disturbance indicator measured. A difference within the range of variability of the method (± 1 RMSE as determined in the preceding section) would indicate that there was little evidence that the disturbance indicator changed between the two end-of-season evaluations.

Precipitation. Multiple linear regression (MLR) techniques were used to estimate the amount of precipitation that occurred at the reaches between the two end-of-season reach evaluations. Such techniques are commonly applied to spatially interpolate and predict precipitation and runoff volumes when such data are not readily available (Hay et al. 1998; Brezonik and Stadelmann 2002; Naoum and Tsanis 2004). The MLR model was built using the daily and monthly precipitation records obtained for the two nearest SNOTEL climate sensors to the reaches. The response variable for the MLR model was the total amount of precipitation between the first and second evaluations as recorded by each of the SNOTEL climate sensors. The covariates for the model included the total amount of precipitation for October and September that occurred at each SNOTEL climate sensor as determined from the PRISM spatial dataset and the total number of days on record. The total number of days on record was equivalent to the number of days between each of the two reach evaluations and served as a way to account for the variable time frame between the evaluation dates. To ensure the MLR model did not over fit the dataset, the model was calibrated using a randomly selected subset of 90% percent of the SNOTEL climate sensors records (n = 61) and validated with the remaining 10% of records (n = 7).

The covariate parameters from the MLR model were then applied to the stream reaches which received two end-of-season evaluations. The variables that went into the model included the total amount of precipitation for October and September that occurred at a reach as determined from the PRISM spatial dataset and the total number of days between the two end-of-season evaluations. The calculated response provided an estimate of the total amount of precipitation which occurred at each of the stream reaches over the respective time frame between the two end-of-season evaluations.

Streamflow data was not available for the reaches in this study so the total precipitation in the catchment served as surrogate for changes to stage height and high discharge events. The precipitation in the catchment was computed for each reach by multiplying the upstream watershed catchment area by the predicted amount of precipitation at the stream reach.

Relation of Disturbance Indicators with Time and Precipitation. I tested whether the changes in livestock disturbance (streambank alteration, stubble height, and woody browse) were related to the amount of time, and precipitation at the reach and in the upstream watershed catchment area. The relations were assessed using linear regression analyses. The dependent variables for the analyses included changes to streambank alteration (MIM and Mod), stubble height, and woody browse. The independent variables included the total amount of time, precipitation at the reach, and precipitation in the catchment that occurred between the two end-of-season evaluations. These analyses were conducted using only the managed reaches because livestock were not at the reference reaches so the changes to the indicators were negligible.

Variability between Years

The reaches that were evaluated in consecutive current years were used to determine if livestock disturbance measures were affected by yearly variations of precipitation. Analyses were conducted separately for MIM and Mod streambank alteration, stubble height, and precipitation. Mean streambank alteration, stubble height, and total precipitation (for the respective water year) were computed for each year of the study. Paired *t* tests were used to determine if the differences between the two years were significantly different from zero. If there was significantly different precipitation for a given year and a corresponding significant difference in the measurement it could be interpreted that precipitation had an effect on that livestock disturbance indicator.

Relationship among Livestock Grazing Indicators and Landscape Conditions

To determine if the pattern of livestock disturbance was a function of climatic and landscape conditions I used MLR techniques to predict streambank alteration and stubble height based on their relation with a number of covariates (Smith 1988; Al-Chokhachy et al. 2010; see Table 1). For this analysis I computed all possible multiple linear regressions using adjusted R^2 with AIC (PROC REG). The most appropriate models were determined through the minimum AIC. The response variables for the models included MIM streambank alteration, Mod streambank alteration, and stubble height. The analyses were limited to these three disturbance indicators as they were evaluated for all reaches during both years of the study and had a sufficient sample size for MLR analysis. If there were strong correlations with the disturbances indicators and the climatic and landscape variables then it would suggest these conditions contribute to the pattern of livestock disturbances within riparian areas.

Relationship among Livestock Grazing Indicators and Grazing Intensity

The ten reaches with time lapsed cameras were used to determine if the livestock disturbance indicators were related to grazing intensity. The relations were tested using linear regression analysis. The independent variable for the analysis was percent of the days with ungulates and was equal the sum of days with livestock and wild ungulates within the riparian area divided by the total number of days containing photographs for each reach. The dependent variables included 2011 disturbances indicators: MIM and Mod streambank alteration, stubble height, and woody browse.

Relationship among Livestock Grazing Indicators and Stream Conditions

I examined the relationship between livestock disturbance measures at the end of the grazing season to long-term conditions of stream habitat. This was done by predicting eight stream characteristics based on their relationship with livestock disturbance. Within in this frame work I first incorporated a number of climatic and landscape covariates that could affect the susceptibility physical habitat within the evaluated reaches (Burnett et al. 2006; Al-Chokhachy et al. 2010; Table 1). I then incorporated livestock disturbances indicators as covariates for the stream habitat attributes to determine if short-term-conditions were related to long-term stream conditions.

All possible multiple linear regressions were computed for each of the stream habitat attributes using adjusted R^2 with AIC (PROC REG). The most appropriate models were determined through the minimum AIC (Akaike in 1974). The response variables for the analysis included width to depth ratio, bank angle, percent undercut banks, bank stability, residual pool depth, pool frequency, percent fine sediment (< 6 mm), and median particle size. The covariates included the climatic and landscape conditions listed in Table 1.

After determining the best covariate models, streambank alteration (MIM and Mod) and stubble height were individually added to determine if the disturbance indicators improved the individual models for each of the stream habitat variables. An improved model would be based on a lower AIC values but the value of this improvement would be further refined by model fit (adjusted R^2) and the disturbance indicator being a significant model parameter. Model improvement would suggest that the indicator had an effect on the individual stream habitat variable.

RESULTS

Indicators of Livestcok Disturbance

Streambank alteration as determined by the four disturbance protocols differed (Table 4). The overall average alteration was 23.5% (SD 20.9, $n = 121$) for MIM, 8.8% (SD 9.5, $n = 121$) for Mod, 26.4% (SD 14.4, $n = 30$) for SLA, and 10.4% (SD 21.2, $n = 27$) for LI. Mean stubble height was 24.2 cm (SD 14.4, $n = 212$) and mean woody browse was 23% (SD 20.1, $n = 133$). The standard deviation was generally as big as or bigger than the mean for the method, indicating that there was high variation in the amount of disturbance among the stream reaches.

Relationship among Streambank Alteration Protocols. The best model describing the relationship between the MIM protocol and the Mod protocol was the non-linear Michealis-Menten model ($P < 0.01$, pseudo $r^2 = 0.94$, $n = 212$, Figure 7). The relation of the two protocols was described by the Michealis-Menten model where $a = 3.9 \pm 0.13$ ($\pm$

1 SE) and $b = 0.03 \pm 0.002$ ($n = 212$). The relation initially increased with a slope approximately equal to three for lower alteration values (where MIM < 42% and Mod < 15%). In this range a 1% increase under the Mod protocol related to an approximate 3% increase with the MIM protocol. For higher alteration values (where MIM > 42% and Mod > 15%) the slope tapered to a value approximately equal to 1.5.

Percent alteration as determined through SLA was nonlinearly related to percent alteration as determined through MIM ($P < 0.01$, pseudo $r^2 = 0.98$) and Mod ($P < 0.01$, pseudo $r^2 = 0.96$). Percent alteration from the SLA method was consistently higher than alteration of the MIM and Mod methods. The slope of the relations initially rose quickly but then flattened off at higher values. The relations between the protocols was again described by the Michealis-Menten model where $a = 1.8 \pm 0.13$ and $b = 0.01 \pm 0.003$ for MIM and $a = 7.3 \pm 0.62$ and $b = 0.07 \pm 0.01$ for Mod ($n = 30$; Figure 8). The relation of MIM and SLA initially increased with a slope approximately equal to 1.5 for lower alteration values (where MIM < 29% and SLA < 35%). The relation of MIM to SLA was nearly equal with a slope of approximately 1 for higher alteration values (where MIM > 29% and SLA > 35%). The relation of Mod and SLA increased steeply with a slope approximately equal to 5.4 for very lower alteration values (where Mod < 6% and SLA < 30%). For Mod alteration values greater than 6%, the slope of the relation was approximately equal to 1.8. The difference of streambank alteration between the SLA and Mod methods was greater than the difference between the SLA and MIM methods, indicating that measures of alteration from the SLA method were more closely related to measures from MIM than those obtained through Mod.

Percent alteration as determined with the MIM ($P < 0.01$, pseudo $r^2 = 0.91$) and Mod ($P < 0.01$, pseudo $r^2 = 0.92$) protocols were nonlinearly related to the LI ($n = 27$; Figure 9). The relations between these protocols were described by the Michealis-Menten model where $a = 5.01 \pm 0.73$ and $b = 0.05 \pm 0.01$ for MIM, and $a = 1.26 \pm 0.17$ and $b = 0.02 \pm 0.01$ for Mod. These estimates indicate MIM overestimated while Mod slightly underestimated streambank alteration when compared to the LI. The relation of MIM and LI initially rose quickly with a slope approximately equal to 3.3 for lower alteration values (where MIM < 42% and LI < 15%). For higher alteration values (where MIM > 42% and LI > 15%) the MIM protocol had approximately two times the amount of streambank alteration as that of the LI protocol with the slope tapering to a value approximately equal to 0.8. The relationship between of Mod and LI was nearly equivalent for lower alteration values (where Mod < 15% and LI < 14%). The relation suggests that a 1% increase under the Mod protocol is approximately equal to a 1% increases in streambank alteration under the LI protocol. For higher alteration values (where Mod >15% and LI >14%) the slope tapered to a value approximately 0.5 suggesting the Mod protocol underestimated alteration at higher disturbance levels when compared to the LI protocol.

Relations among Streambank Alteration, Stubble Height, and Woody Browse. The four streambank alteration protocols, MIM, Mod, SLA, and LI, had similar trends with higher measures of stubble height being associated with lower streambank alteration (Figure 10). In all cases, streambank alteration rapidly decreased with increased stubble height and then flattened out above a threshold value of stubble height. The threshold valuie at which stubble height flattened was 26 cm for MIM, 26 cm for Mod, 27 cm for

SLA, and 44 cm for LI. At lower stubble heights the slope of the relations were approximately -1.5, -0.7, -1.7, and -0.5, with MIM, Mod, SLA, and LI, respectively. The relationships among streambank alteration and woody browse varied among the four methods. Overall, MIM, Mod, SLA, and LI alteration increased with percent woody browse, but the relations were weak and markedly differed among the four methods. At lower levels of woody browse the relation with streambank alteration had a slope of approximately 0.6 with MIM, 0.2 with Mod, 1.6 with SLA, and 0.4 with LI. The relationship began to taper and flatten at approximately 35% woody browse for MIM and Mod methods and approximately 25% browse with the LI method. The SLA maintained a positive relation for all levels of woody browse but the slope of the relation declined to approximately 0.7 for woody browse values greater than 10%. There was an overall negative trend in the relation between woody browse and stubble height (Figure 11). The slope of the relation was approximately -0.5, suggesting that a one centimeter decrease in stubble height is approximately equal to a 0.5% increase in woody browse. The relation did not have a threshold value in which the slope changed dramatically.

Observer Repeatability

Observer repeatability differed among the streambank alteration protocols (MIM, Mod, SLA, and LI), stubble height, and woody browse (Table 5). The LI protocol for measuring streambank alteration had the lowest variability of all methods assessed; observers consistently arrived at similar results of streambank alteration (RMSE = 1.8%) and the variation among reaches was the most distinguishable from that among observers (S:N = 15.2). Of the three rapid assessments for evaluating streambank alteration Mod was the most repeatable as determined through the RMSE (4.5%), followed by SLA

(RMSE = 6.9%), and then MIM (RMSE = 7%). Reach variability (signal) and observer variability (noise) followed similar trends as the RMSE yet the proportion of that variability was not equal among the protocols. The MIM and SLA methods for evaluating streambank alteration had high repeatability with a S:N ratio of 8.4 and 8.8, respectively while the Mod method had a moderately repeatable S:N ratio of 3.3. Stubble height had moderate repeatability with a RMSE of 8.3 cm and S:N ratio of 2.7. Woody browse had the greatest variability of all the disturbance indicators evaluated (RMSE = 14.5%, CV = 65.9%); measurements of woody browse were nonrepeatable having nearly as much variation among observers as that among stream reaches (S:N = 1.3).

End-of-Season Variability

Overall, streambank alteration (MIM and Mod) changed at most of the reaches, stubble height changed at very few reaches, and woody browse changed at half of the stream reaches that were evaluated on two separate dates following the 2011 grazing season. The changes to the disturbances indicators were inconsistent with some reaches having increased and other reaches having decreased measurements of alteration. Streambank alteration as determined with MIM increased at six reaches, decreased at 18 reaches, and had no change at 10 reaches. Streambank alteration as determined with Mod increased at eight reaches, decreased at 12 reaches, and had no change at 14 reaches. Most of the changes for stubble height fell within the range of observer variability between the two evaluations, with five reaches having increased and three having decreased measurements. Woody browse increased at six reaches, decreased at nine reaches, and had no change at 15 of the evaluated reaches.

Precipitation. The MLR model for predicting the total amount of precipitation that occurred at the SNOTEL climate sensors had good fit and therefore could be applied to the stream reaches ($P < 0.01$, adjusted $R^2 = 0.7$). The model used to predict the amount of precipitation was:

$$Precipitation = 0.07 + 0.026(time) + 0.526(precip_{\ Sep\ +\ Oct}) \quad \textbf{[6]}$$

with *time* being the total number of days between the first and second evaluations and *precip* being to the total amount of precipitation (cm) for September ($_{Sep}$) and October ($_{Oct}$) as determined from the PRISM spatial datasets.

Relation of Disturbance Indicators with Time, Precipitation, and Precipitation Volume. The regression analyses showed different relationships to livestock disturbance changes (streambank alteration, stubble height, and woody browse) and the three end-of-season variables (time, reach precipitation, and catchment precipitation) at the stream reaches (Figure 12). No single temporal variable showed a significant effect on the four livestock disturbance measures. Streambank alteration as determined through MIM (P = 0.04, r^2 = 0.14) and Mod (P = 0.09, r^2 = 0.09) significantly decreased as post season precipitation within the catchment above the evaluated reach increased. Browse to woody vegetation significantly increased over time (P = 0.02, r^2 = 0.18) and with increased precipitation at the reach (P = 0.02, r^2 = 0.20). Changes to stubble height had no relation with time or precipitation variables.

Repeat Photographs. Of the 34 reaches that had a second evaluation 29 reaches had repeat photographs that could be visually inspected for continued grazing, increased stream stage, and changes to livestock disturbances. Eleven of the 29 reaches had visual evidence that livestock grazing continued after the first evaluation (e.g., Figure 13).

Indications of continued grazing were noted through decreased stubble height, increased hoofprints or shearing, and presence of new cow patties in the repeat photographs. There was visual evidence that stream stage had increased at 14 of the reaches between the two evaluation (e.g., Figure 14 and Figure 15); of these reaches at least five had evidence that stage height had risen and then resided (evidence though new scour lines, ponding within the riparian area, and water flow patterns over riparian vegetation). Estimates of stage height increase ranged from approximately 2 cm to 60 cm. The photographs also indicated that livestock alterations (hoof prints, shearing, and trailing) had become less evident at 17 of the reaches (e.g., Figure 15 and Figure 16). It was very apparent that changes to alterations were an effect of weathering events including splash detachment (i.e., precipitation) and soil erosion from rising and residing streamflows (e.g., Figure 16 and Figure 17). Many photographs showed substantial evidence of soil erosion between the two evaluations, the rate of erosion varied from reach to reach; the degree of the erosion ranged from minor with hoof prints and shears less evident, to moderate with displaced soils washed away from high flows, to substantial with substantial amounts of sediment transported away from banks exposing new roots and carrying portions of bank materials downstream. Eight of the 29 (28%) reaches had repeat photographs which showed evidence of both increased alteration from continued grazing and decreased alteration resulting from weathering of the soil through precipitation and high flow events.

Variability between Years

There was significantly greater precipitation ($P < 0.01$) and significantly lower alteration as determined with both the MIM ($P < 0.01$) and Mod ($P < 0.01$) protocols in

2011 than in 2010 (*n = 63;* Table 6). Mean alteration was 15% (SD 12.7) for Mod and 35.4% (SD 25.4) for MIM for the first year the evaluations. The following year these values decreased by nearly half the disturbances to 7% (SD 6.3) alteration for Mod and 20.9% (SD 17.5) alteration for MIM. There was no statistical evidence that stubble height differed between the two years. Mean precipitation was 62.8 cm (SD 23.6) for the 2010 water year 2010 and 74.4 cm (SD 32.3) for the 2011 water year, therefore on average each reach had approximately 11.6 cm more precipitation in 2011 than in 2010. The monthly distribution of precipitation indicated that much of the additional precipitation for 2011 occurred as snow accumulation over the winter months, November – March, and as rain on snow during the spring, April – May (Figure 18). The summer months, June – August, had lower precipitation in 2011 than that of 2010. Although no direct analysis was done, it can be inferred that the increased precipitation in 2011 lead to decreased use of riparian areas by livestock and wild ungulates.

Relationship among Livestock Grazing Indicators and Landscape Conditions

Model fit was low and structure varied among the multiple linear regression models for the individual disturbances indicators (adjusted R^2 range = 0.10-0.14; Table 7). Streambank alteration for MIM was higher on small, low gradient reaches that were within catchments of high drainage densities, low precipitation, and low temperatures. Streambank alteration as measured with Mod had similar model structure as MIM but Mod evaluations were not affected by stream gradient. Stubble height was higher on steep gradient sinuous streams within catchments of high annual precipitation and temperature, and low percent igneous geology. Overall there was little evidence of a consistent pattern of livestock disturbance with environmental conditions. The climatic variables, average annual precipitation and temperature, were the only attributes that were included in all of the models; with greater annual precipitation and temperature resulting in reduced streambank alteration and greater stubble heights.

Relationship among Livestock Grazing Indicators and Grazing Intensity

The livestock disturbance indicators were linearly related to the percent days with ungulates in the riparian area. Streambank alteration as determined through MIM (P = 0.06, r^2 = 0.37) and Mod (P = 0.07, r^2 = 0.36) significantly increased, and stubble height significantly decreased (P = 0.09, r^2 = 0.32) as the percent of days with ungulates in the riparian area increased (Figure 19). The slopes of the relations were 0.46 $\pm$ 0.99 for MIM, 0.17 $\pm$ 0.37 for Mod, and -1.56 $\pm$ 0.60 for stubble height. These relations suggest a 1% increase of the percent days with ungulates in the riparian area will result in a 0.46% increase of streambank alteration through MIM, and a 0.17% increase of streambank alteration through Mod. Likewise, a 1% increase of the percent of days with ungulates in the riparian will result in a decrease of stubble height by 1.6 cm. There was insufficient statistical evidence of a relation between percent woody browse and grazing intensity (P = 0.15, r^2 = 0.3).

Relationship among Livestock Grazing Indicators and Stream Conditions

Model structure explaining the condition of stream habitat attributes varied considerably (Table 8). This suggests that watershed and climatic attributes affected individual stream attributes differently regardless of the level of livestock grazing. Model fit to predict individual stream attributes with only watershed and climatic attributes ranged from 0.07 to 0.5 (R^2). Reaches with larger bankfull widths had greater width to depth ratios, lower bank stability, deeper pools, less fine sediment, and larger median particle sizes. Highly sinuous reaches had more acute bank angles with more undercut banks and lower bank stability. Sinuous reaches also had more percent pools with finer sediment and smaller medium particle size. Steeper gradient reaches had greater width to depth ratios with more obtuse bank angles and greater abundances of shallow pools. Reaches with steeper slope of the segment had greater width to depth ratios with more obtuse bank angles and a lower abundance of undercuts. Steeper sloped segments also had greater channel roughness (decreased fine sediment and larger median particle size) and pools that were shallower and less abundant. Reaches with a high density of roads at the segment had lower pool frequency and less fine sediment. High forested cover of the segment contributed to shallow pools that were less abundant and larger median particles size. Catchments with high drainage density had wider and shallower reaches with pools that were shallow and less abundant. Stream reaches receiving high precipitation within the catchment had lower width to depth ratios, more acute bank angles with more undercuts, deeper and more abundant pools, and less channel roughness (more fine sediment and smaller median particle size). Reaches with higher temperatures within the catchment had more obtuse bank angles, lower percent undercut banks, more deep pools, and more fine sediment. Stream reaches within catchments with a high proportion of igneous geology were found to have more obtuse bank angles, lower bank stability, more pools, and smaller median particle sizes. Catchments with a greater proportion of sedimentary geology were found to have more obtuse bank angles with a lower percent of undercut banks, more deep pools, and smaller median particle sizes at the reach scale.

After accounting for watershed and climatic attributes, model improvement varied considerably with the addition of individual short-term indicators of livestock disturbance (Table 8). After accounting for landscape and climatic conditions MIM streambank alteration significantly improved the model for three stream habitat attributes (width to depth ratio, bank angle, and percent undercut banks) while the addition of Mod streambank alteration significantly improved the model for only one stream attribute (width to depth ratio). Stubble height had the greatest effect on stream conditions with model improvement of four stream habitat attributes (bank angle, percent undercut banks, bank stability, and residual pool depth). Stream reaches with higher MIM and Mod streambank alteration had significantly higher width to depth ratios (MIM with $p < 0.01$, $R^2 = 0.54$; Mod with $p < 0.01$, $R^2 = 0.54$). Bank angles became more obtuse with increased MIM streambank alteration ($p = 0.03$, $R^2 = 036$) and decreased stubble height ($p = 0.03$, $R^2 = 0.36$). Reaches with lower amounts of MIM alteration and higher stubble heights had higher percentages of undercut banks (MIM with $p = 0.05$, $R^2 = 0.29$; stubble height with $p = 0.03$, $R^2 = 0.29$). Bank stability improved ($p = 0.02$, $R^2 = 0.08$) and pools were deeper ($p < 0.01$, $R^2 = 0.47$) on stream reaches with greater stubble heights. There was little evidence that pool frequency, percent fine sediment less than 6 mm, or median particle size (d_{50}) were affected by streambank alteration or stubble height disturbance indicators.

DISCUSSION

This study presents strengths and weaknesses of using annual short-term disturbance indicators as management objectives for grazing. I found results were dependent on the specific protocol (i.e., MIM, Mod, SLA, and LI), which indicator was used (i.e., streambank alteration, stubble height, and woody browse), the observer, and when the evaluations were conducted. While there were many factors affecting outcomes, these year-end measures were related to grazing intensity and long-term stream conditions.

Streambank Alteration Protocols

I found that differences in protocols affected mean estimates of streambank alteration in a manner similar to those described by Heitke et al. (2008). The three rapid approaches (MIM, Mod, and SLA) are an index of streambank alteration whereas the LI method is a direct measure of streambank alteration in that it directly measured the percent of the greenline altered (Kaiser 1983; Bengeyfield 2006). The MIM and SLA methods treat a line that barely intercept a hoofprint as if it were 100% altered (presences/absence; Heitke et al. 2008). In contrast, the Mod method, with a finer resolution, may indicate that only 5% a line was altered (one increment of a line intercepts alteration). Index values derived with MIM will always equal or exceed Mod and index values derived with SLA will always equal or exceed MIM and Mod. The difference of these protocols reflects how streambank alteration was evaluated and summarized rather than differences in the actual disturbance (Heitke et al. 2008).

The differences among these protocols when evaluating the same reach can be problematic when a specific standard is applied. For example, the application of a standard to maintain streambank disturbance at or below 20% alteration might be a very conservative standard for reaches evaluated with SLA. Alternatively, a 20% threshold standard may have adverse impacts to reaches evaluated with Mod. The difference of outcomes in the field among methods means that any objective or standard for streambank alteration must be based on the protocol used.

In this study I found that MIM and SLA exceeded the amount of alteration along the greenline as determined by LI. In contrast Mod mimicked the results of LI in the range of 0 to 20% but underestimated alteration at higher levels of disturbance. While not directly tested, the underestimation likely occurred because Mod sampled a different area than the LI method. The LI was placed linearly along the greenline – an area that is very susceptible to livestock alteration. In contrast MIM, Mod, and SLA evaluated an area that included the greenline along with other stream side features which could potentially be less susceptible to hoof alterations such as steep 90^{o} banks, flowing water, or the streambed materials. When the greenline was adjacent to the water's edge (e.g., small streams and E channels; Rosgen 1994) the lines of the rapid assessments extend over water. In accordance with MIM and SLA protocols any portion of the sample width that extended over water was ignored (USDI-BLM 1996; Burton et al. 2011). This is problematic because it results in a variable sample area that is dependent upon stream characteristics. Take for example a scenario of two stream reaches: the first reach with slowly sloping banks and the entirety of the greenline approximately one meter away from water's edge (e.g., B channels at baseflow; Rosgen 1994); the second reach with the entire greenline adjacent to water's edge (e.g., E channel; Rosgen 1994). In the first reach the entire sample plot is susceptible to being altered since all of it is in an area livestock are likely to disturb. In the second case only half of the plot area is susceptible to disturbance therefore the probability of detection is decreases by half. The LI method avoids the issue of a variable sample area as the continuous line intercept is placed directly on top of the streambank never extending over the water's edge. While the difference between the surveys along a line versus an area is problematic for all of the rapid evaluations, the variable sample width has greater consequence with the Mod protocol. This problem can be illustrated by assuming banks of both the streams described above were 100% covered by signs of livestock disturbance. In the first stream, where all the plots fall 100% on land, the MIM, Mod, SLA, and LI would all record 100% disturbance. In the second stream half of the plots would fall over water. Because the MIM and SLA treat any part of the line as if it were altered, both methods would conclude 100% alteration. Similarly, the LI evaluation would also arrive at measures of 100% alteration. The Mod protocol, however, would find 50% alteration since half of the sample area would fall over water and no measurement would be taken.

The underestimation occurs because Mod allows for index values (individual increments of a line) to be recorded for areas other than the streambank. The problem is less severe with MIM and SLA because at least some portion of the index value (sample line) always extends over the streambank and because these methods inherently overestimate the amount of the streambank altered by livestock. Because of the strong congruence between the LI and Mod on reaches where all samples occur on dry land; Mod will generally underestimate bank alteration on reaches where greenline is predominantly on or near the water's edge.

Indicators of Livestock Disturbace

The three indicators of livestock disturbance (streambank alteration, stubble height, and woody browse) were related to each other but the relations exhibited considerable variation. As expected streambank alteration decreased as stubble increased and woody browse decreased. These general trends were observed across all four alteration protocols. Likewise, woody browse decreased as stubble height increased. While these general trends were observed, many reaches fell outside of what was expected suggesting the indicators may respond differently at different sites (Bryant et al. 2006, Burton et al. 2011).

The scatter in the relationships among the three livestock disturbance indicators (streambank alteration, stubble height, and woody browse) suggests that is it is possible for a reach to have low disturbance with one short-term indicator (e.g., low streambank alteration) while exceeding disturbance standards with another indicator (e.g., low stubble height). Such outcomes occur because the potential of an individual indicator to respond to livestock grazing is affected by inherent characteristics of riparian vegetation and channel conditions (Bengeyfield and Svoboda 1998; Bryant et al. 2006). One underlying cause is that stubble height is limited to vegetation potential. Reaches with a high abundance of low growing forbs such as violet (*Viola sp.*) and brook saxifrage (*Saxifraga odontoloma)* will have low stubble height measures regardless of livestock grazing in the riparian area. Another factor affecting vegetation potential is the amount of available light to the understory (Anten and Hirose 1998; Lieffers and Stadt 1994). Even without livestock grazing the height of many palatable riparian plants, such as blue joint reed grass (*Calamagrostis canadensis*), will be less in a closed canopy system (e.g., cedar forest) than in an open canopy system (e.g., open meadow). The palatability of individual plant species can also have an effect on the amount of browse to riparian vegetation (Kauffman et al. 1983a; Alldredge et al. 2001; Bryant et al. 2006; Butler and Kielland 2008). Stubble height and woody browse summaries may indicate low disturbance on stream reaches with a high abundance of less palatable vegetation (e.g., alder [*Alnus sp.*], Woods' rose [*Rosa woodsii*], and thistle [*Cirsium sp.*]) and a low abundance of highly palatable vegetation (e.g., willow [*Salix sp.*], sedge [*Carex sp.*], and Kentucky blue grass [*Poa pratensis*]) regardless of livestock use or browse to more palatable plant species. Additionally, there are conditions in which streambanks are resistant to penetration (e.g., cohesive soil containing clay along a dry or entrenched channel) or are impervious to disturbance (e.g., bedrock or boulder armored stream channels). Even at very high grazing intensities such conditions will contribute to lower streambank alteration.

This study provides clear evidence that each of the indicators evaluated provides different information about a grazed reach. Since each of these indicators plays an important role in riparian health and stream function all three indicators (streambank alteration, stubble height and woody browse) should be monitored. Streambank alteration gives information's about sediment additions to the stream, the mechanical breakdown of banks and excessive erosion that can alter channel morphology which can ultimately lead to increases in stream temperature and degrade habitat for aquatic species (Platts 1991; Clary et al. 1996; Neary and Medina 1996; Bengeyfield 2006). Healthy riparian vegetation as evaluated by stubble height stabilizes banks, slows bankfull flows, filters out sediment, increases soil moisture, and supports base flows (Clary and Webster 1989; Welsh 1991; Neary and Medina 1996). Healthy woody vegetation has strong deep root systems that stabilize banks, shade streams, and provide woody debris which support food-web dynamics and create habitat diversity for aquatic species (Welsh 1991). Each of these indicators is essential to riparian function; excessive disturbance to any one of these indicators could be detrimental to overall stream health. It is important that land managers take into account all three indicators when making management decisions and assessing end-of-season conditions.

Observer Repeatability

Sources of variability identified in previous studies of field measurements for stream attributes include differences and duration of training (Hannaford et al. 1997; Olsen et al. 2005; Whitacre et al. 2007; Heitke et al. 2008), professional background (Heitke et al. 2008), differences in the protocol used (Whitacre et al.2007; Heitke et al. 2008; Roper et al. 2010), and the number of measurements taken (Roper et al. 2002; Olsen et al. 2005). In this study measurements of streambank alteration and stubble height were relatively repeatable while methods for evaluating woody browse were nonrepeatable. When disturbance threshold standards are applied or set as goals, it is important that all observers consistently arrive at the same measurement (i.e., low RMSE) and variance from reach to reach is distinguishable from that of the observer (i.e., S:N > 6.5). The intensive assessment (LI streambank alteration) was the only method in this study that met these criteria. None of the rapid assessments in this study (streambank alteration [MIM, Mod, and SLA], stubble height, and woody browse) were both repeatedly measured and distinguishable from the differences among stream reach conditions (low RMSE and S:N > 6.5).

The training of all methods and protocols used in this study was limited to four hours in 2010 and twelve hours in 2011. The variation associated with the measurement of short-term livestock disturbances indicators could potentially be reduced through more intensive trainings. Roper et al. (2010) suggested that when a protocol or method is found to have poor performance, improvement can only occur if the protocols are regularly evaluated and training and oversight are thorough and ongoing.

Two general trends of the four streambank alteration protocols were 1) variability increased as the increment of measure increased and number of measurements recorded decreased and 2) variability increased as mean streambank alteration increased. Although the LI method had the lowest variability the measure did not incorporated sources of variability of the other methods. It evaluated alteration along the entire reach rather than every 2.75 m. Because observers recorded alterations along a single fixed line most of the variability of the LI can be attributed to the among observer determination of hoof alterations. In addition to this variability the three rapid assessments (MIM, Mod, SLA) incorporated the among observer variability associated with sample locations (i.e., variability of quadrat placement). The large differences in variability of streambank alteration between a time intensive assessment (LI method) and the rapid assessments (MIM, Mod, and SLA) can thus be attributed to differences in 1) the number of measurements sampled, 2) the scale or resolution of measurement, and 3) the fact that these other approaches sample an area versus a fixed line.

The primary difference between the four protocols for assessing streambank alteration was the maximum number of measurements that were recorded at an individual stream reach and resolution of those measurements. The number of sample locations (i.e., quadrat frames placed) at an individual reach was equal for each of the rapid assessments (MIM, MOD, and SLA) evaluated, yet the number of measurements recorded at an individual sample location differed. For the rapid assessments the SLA had the lowest number of measurements recorded with one linear measure taken per 2.75

m of streambank, followed by MIM with five measures subsampled per 2.75 m of streambank, and then Mod with 100 measures subsampled per 2.75 m of streambank.

The number of measurements recorded for an attribute has been identified in the literature as a source of variability in stream monitoring (Roper et al. 2002; Olsen et al. 2005). As the number of measurements per given increment increases so does the resolution of the measurements. The SLA had the lowest measurement resolution with a length of 91.4 cm, followed by MIM with 20 cm, and Mod with 2 cm. The LI method had the highest resolution with measurements recorded to the nearest 1 cm increment along continuous line. The concept of resolution and its relation to accuracy and precision are commonly applied to spatial data datasets (e.g., digital elevation models [DEM], light detection and ranging [LiDAR], and photographs) for vegetation (e.g., Hosoi and Omasas et al. 2007) and stream channel attributes (e.g., Wheaton et al. 2010). Many studies have found that accuracy and precision (variability) improve with higher resolution (Gao 1997, Horritt and Bates 2001, Shi et al. 2012). Although the application of the term resolution is generally applied to spatial data, the same general concept applies. In this research I found that method variability (RMSE) decreased and S:N increased as the number of measurements recorded at a reach increased.

Woody browse had the highest observer variability of the three livestock disturbance indicators. This variability likely contributed to the weak relations among other disturbance indicators and the insignificant relation grazing intensity. Hall and Max (1999) also found high variability in measurements of livestock use to riparian woody plants. However, the trends in this study may be more reflective of an inadequate sample design rather than inherent variability associated with browse. Measurements of woody browse were limited to four shrub types; the lack of an "other shrub" category was problematic as few observers had experience with shrub identification prior to this study. I found seven reaches in which one observer recorded woody browse values and the second observer recorded no data indicating a misidentified shrub type by at least one of the observers. Furthermore the shrubs selected for woody browse evaluations overweighed utilization to non-palatable shrubs such Alder (*Alder sp*), Birch (*Betula sp.*) and Dogwood (*Cornus sericea*) and did not include many palatable shrubs such as Cherry (*Prunis sp.),* antelope bitterbrush *(Purshia tridentate)*, and service berry (*Amelanchier sp.*) which would have likely demonstrated stronger relations with the other disturbance indicators and grazing intensity within the riparian area. It is clear a more comprehensive definition of the method and training are needed.

The method for evaluating stubble height in this research differed from more commonly applied methods in that measurements were taken on all herbaceous vegetation rather than key species (USDI-BLM 1996; Bryant et al. 2006; Burton et al. 2011). Key species are generally limited to a few native, palatable, hydric, and deep-rooted or rhizomatous species that serve as an indication of change and are based on specific management objectives (e.g., *Carex sp*.; USDI-BLM 1996; Burton et al. 2011). Although no formal investigations were conducted it is proposed that stubble height evaluations limited to palatable vegetation types would have demonstrated stronger relations with streambank alteration and grazing intensity, and measurements would have differed between wet and dry years. However, the species level plant identification necessary for key species measurements would likely have resulted in higher variability mimicking that of woody browse, which required only genus or family recognition by the observer. Furthermore, key species measures generally ignore nonnative vegetation, such reed canary grass (*Phalaris arundinacea*) and Kentucky blue grass (*Poa pratensis*), that are found in high abundance in many riparian communities (Winward 2000) and provide some type of stabilization along the streambanks (Binns 1994). Therefore, it is likely that stubble heights on key species would have been less informative of long-term stream conditions such as bank stability and bankangle.

The use of key species was not feasible in this study because selections of individual key species are dependent on local vegetation types and would vary from reach to reach. Furthermore, protocols for identifying, selecting, and using key species are difficult to train and would have required that all participating observers had the knowledge of an experienced field botanist. It was important that the protocols implemented in this study could easily be taught to observers with no experience and could be broadly applied to the large scale study area of the Interior Columbia River Basin. In practice protocols should always be easy to train and broadly applied, yet it is also important that protocols do not simplify methods to the extent that they no longer provide useful information about the disturbances being evaluated.

End-of-Season Variability

In measuring the cumulative effects of grazing agencies make at single evaluation of alteration within a week of the removal of livestock from a pasture. This assumption is tenable if measurements over this timeframe are within the range of variability found among observers conducting evaluations at the same time. In this study I found streambank alteration and woody browse varied considerably while stubble height remained relatively constant between the two separate end-of-season evaluations. The changes that occurred between visits were not consistent among the reaches indicating that other factors likely contributed to the differences between the two end-of-season evaluations.

Measurements of streambank alteration had the largest amount of variability between the two end-of-season evaluations; the variability was affected by the precipitation in the watershed catchment. This was expected because the volume of precipitation in the watershed affects runoff and is positively correlated with stream discharge (Ward and Trimble 2004). High discharge events can cause substantial erosion through shear stress of the water on the streambanks (Trimble 1994) or as the water levels reside because of rapid drawdown of the water table in the banks (Simon et al. 1999; Zaimes et al. 2006). At the very least, this will increase the difficulty of determining whether streambank alteration is from the current year or from the previous year. The repeat photographs of the reaches provided evidence that changing water levels caused individual hoofprints to become less evident and smooth vertical shears undetectable. Inference from these findings should not be limited to end-of season precipitation events. Low order mountainous streams, such as those used in this study, have irregular flood patterns with numerous peaks that are influenced by daily precipitation events throughout a season (Junk et al. 1989). It is likely that any large precipitation event within the grazing season would result in decreased measurements of streambank alteration. Within season variation of streambank alteration was also observed by Laine (2011) in a study of five streams in central Idaho. Although the reasons were not discussed, reaches in that study had up to 30% decreases of MIM streambank alteration within the gazing season (Laine 2011, fig. 10a-e). Because of high within season variation of streambank alteration, it is important that land managers monitor frequently throughout the grazing season so the observations can be used as a trigger to move cattle when conditions exceed the allowable disturbances levels. Large changes to measured alteration were observed in as little as 10 days in this study; so it is equally as important that end-of-season evaluations occur on or as close as possible to the day cattle are removed from the pasture.

Stubble height remained relatively constant between the end-of-season evaluations and did not change as an effect of time or precipitation events at the end of the grazing season. This was expected because the evaluations took place at the end of the growing season therefore very little to no vegetation growth would have occurred. Additionally, measures of vegetation height cannot be affected by erosional processes such as those observed with streambank alteration.

Woody browse was affected by both time and precipitation. The second reach evaluations took place during the second week of October; pictures from the plant cameras indicated that some of the precipitation events were snow fall events. Several of the repeat photographs indicated that leaves had begun to drop at the time of the second evaluation. It is conceivable that effects of seasonality (time) may have contributed to the observers' perception of woody browse. The increase in woody browse may have also been attributed to continue grazing by livestock and wild ungulates; however, if this were true one would have expected larger variations in stubble height between the two end-of-season evaluations. Similar to stubble height, browse to woody vegetation would not have been affected by the increased streamflows such as streambank alteration.

Several reaches in this study were found to have more livestock disturbances during the second evaluation. This can be is attributed to continued grazing by livestock on the reaches following the first evaluation. This study provides evidence that livestock remain in many allotments after the take out date. The continued grazing likely contributed to the excessive scatter in the relations between the livestock disturbance indicators and end-of-season time and precipitation variables. If livestock remained within the riparian area, streambank alteration could have remained high regardless of the amount of alteration that had been washed out from precipitation events.

Variability among Years

Yearly variation in precipitation can influence the distribution of livestock across the landscape (Roath and Krueger 1982; Marlow and Progacnik 1986). In this study, I found that streambank alteration was much higher during the drier year of 2010. During years of limited precipitation the overall biomass and palatability of available upland vegetation decreases (Pitt and Heady 1978; Roath and Krueger 1982; Ballard and Krueger 2005). Consequently livestock congregate in riparian areas much earlier in the grazing season and remain for longer durations of time throughout out the season (Roath and Krueger 1982). It is important that land managers consider yearly variation of precipitation as stocking rates that maintain moderate livestock disturbance during a wet year can have adverse impacts during dry year (Holecheck 1988). To reduce livestock impacts it may be necessary for land managers to adjust stocking rates during years with lower precipitation (Marlow and Progacnik 1986).

Climatic and Landscape Conditions

Overall I found that climatic and landscape conditions were weakly related to pattern of livestock disturbance across the Interior Columbia River Basin. Of the conditions that were evaluated, climatic characteristics explained the most variability for both stubble height and streambank alteration indicators. Spatial distributions of temperature and precipitation can have substantial effects on vegetation type and plant growth across the landscape (Sala et al.1988; Smith and Huston 1989). When these climatic factors are limited the quantity and quality of the upland vegetation is also limited (Sala et al. 1988). Therefore it is conceivable that livestock would be more dependent on riparian vegetation in cooler arid environments than in warmer mesic environments.

Although landscape characteristics did contribute to the pattern of livestock disturbance within riparian areas, the overall proportion of variability explained by those characteristics was low suggesting that it is possible to have low livestock disturbance in cold arid areas and high disturbance in warm mesic areas. The lack of a strong pattern indicates that grazing intensity and past management practices played a large role in the amount of livestock disturbance to the riparian areas. Such a statement should not be taken to suggest the management across a wide span of landscapes takes the same amount of effort but that individual managers can control livestock disturbance regardless of the landscape characteristics of the area they are managing.

Grazing Intensity

The time lapse cameras provided quantifiable evidence that measures of streambank alteration and stubble height were related to grazing intensity, but these relations were weaker than expected. This is likely attributable to the large gaps of photographs resulting from observers misplacing secure digital cards and cameras getting knocked over in the field. The pattern of livestock use within riparian areas varies throughout the grazing season (Marlow and Progacnik 1986, Roath and Krueger 1982; Ballard and Krueger 2005). Some of the reaches had photographs missing at the beginning of the season while others were missing photographs taken toward the end of the season. This shortcoming made it difficult to determine exactly how many and the frequency to which livestock were within the riparian areas.

Despite the missing photographs, the time lapse cameras were an effective way of to capture riparian use by wild ungulates and livestock. Generally information regarding use is limited to the numbers of livestock which were permitted within an allotment or pasture. These numbers do not take into account trespassing livestock, wild ungulates, or the frequency to which these ungulates are within the riparian area. Observational studies are very time consuming and are often limited to a few study locations (e.g., Marlow and Progacnik 1986, Roath and Krueger 1982; Ballard and Krueger 2005). For this study, I used timelapse cameras at a very small subset 10 reaches to gain a general estimate of grazing intensity. Such techniques could easily be applied to larger sample sizes. Moreover, timelapse cameras are a cost effective tool that can be used to identify grazing intensity as well as the temporal and spatial distribution of livestock within a management unit.

Long-Term Stream Conditions

The short-term indicators of livestock disturbance were found to be related to the condition of stream attributes. The relations that were observed were in the direction that was expected, suggesting the levels of streambank alteration and stubble height are indicative of long-term stream conditions. Like to others, I found channel width to depth ratio (Platts 1981a; Hubert et al. 1985; Stuber 1985; Overton et al. 1994; Matthews 1996; Knapp and Matthews 1996; Clary 1999), bank angle (Platts 1981a; Myers and Swanson 1995; Knapp and Matthews 1996; Belsky et al. 1999; Clary and Kinney 2002), undercut banks (Kauffman et al. 1983b; Overton et al. 1994; Myers and Swanson 1995; Knapp and Matthews 1996), bank stability (Platts 1981a; Kauffman et al. 1983b; Overton et al. 1994; McIver and McInnis 2007), and pool depth (Hubert et al. 1985; Myers and Swanson 1994) were affected by differences in livestock grazing intensity within the season.

These long-term stream responses occur because of the indirect effects from vegetation removal and direct effects from livestock hooves. The combination of grazing and trampling reduces riparian vegetation through defoliation and mechanical disturbance (Hofman and Ries 1991; Trimbel and Mendel 1995). Compaction of the banks prevents infiltration of water and air to roots substantially reducing vegetation viability (Clary 1995) and can alter species composition from deep rooted to shallow rooted (Reed and Peterson 1961; Trimble and Mendel 1995). The culmination of these effects are the loss of the above and below ground biomass necessary to slow stream flows, filter sediments, and stabilize banks (i.e., degraded riparian function; Micheli and Kirchner 2002; Burton et al. 2011).

The direct force from livestock hooves shears away vertical banks, causes undercut banks to collapse, and creates ramps (trails) along the streambank (Trimble 1994; Bohn 1998; Clary and Kinney 2002). The mechanical breakdown of the bank is then accelerated through hydraulic action along the unprotected streambanks (Trimble

1994) creating a sloping bank profile representing a fundamental change to channel morphology and a general degradation of stream habitat condition (Bohn 1998; Clary and Kinney 2002).

Like others I found insufficient evidence of that percent pools (Kershner et al. 2004b), percent fine sediment (Overton et al. 1994; Knapp and Matthews 1996; Clary 1999), or median particle size (Ranganath et al. 2009) were affected by livestock grazing. This is inconsistent with other studies that have reported decreased percent pools (Myers and Swanson 1996; Magillian and MacDowell 1997), increased fine sediment (Hubert et al. 1995; Myers and Swanson 1996), and decreased median particle size (Raymond and Vondraccek 2011) with grazing. The failure to find an effect from livestock disturbance on substrate (median particle size and percent fine sediment) may reflect that these conditions are not only affect by grazing but may also be affected by other management activities occurring within the upstream catchment such as mining or timber harvest (Rinne 1988; Clary 1999; Ranganath et al. 2009). Another possible reason for the lack of a distinguishable relation is grazing may simplify the channel morphology in a manner that allows more efficient sediment transport. The possible interactions among stream attributes with livestock and other impacts make it difficult to isolate the impact of livestock disturbance.

The capacity to detect effects from livestock grazing may also have been limited by the temporal disconnect between the measurements of livestock disturbance and evaluations of stream conditions. Due to the availability of the PIBO-EMP dataset, field measurements of the stream attributes often took place on a date prior to field measurements for the disturbance indicators. This is likely why the stream attribute models had limited improvement with the model fit (R^2) with the addition of the disturbance indicators. That I still found relations with streams conditions suggests the patterns of livestock disturbance observed in this study were likely reflective of long-term management practices within the reach; meaning a large portion of the stream reaches with high disturbance in 2010 and 2011 likely had high disturbance in preceding years. The temporal disconnect between the stream habitat surveys and disturbance measures, however, added error to the models that may have precluded detections of some relationships.

Because modifications to channel morphology can degrade aquatic habitat, it is important that the method selected for monitoring is informative of long-term stream conditions. I found streambank alteration as evaluated through the MIM method was more sensitive to changes in long-term stream conditions than the Mod method. Since both measures are related to livestock grazing this variation is likely attributed greater signal in the MIM approach and the finding that streambank alteration measurements decreased (become less evident) as a result of erosional processes within the grazing season. Consequently MIM, which inherently overestimates the amount of streambank alteration present at the time of an evaluation, may be more expressive of collective livestock disturbances throughout the season.

CONCLUSIONS

The use of standards in combination with monitoring is, and should remain, an important management tool to minimize the impacts of grazing in riparian areas (Bengeyfield and Svoboda 1998; Clary and Leininger 2000; Heitke et al. 2008). It is important that standards for any indicator of livestock disturbance not only facilitate healthy riparian conditions but also identify the protocol to be used to evaluate that indicator (Heitke et al. 2008). The suit of indicators and associated protocols used to evaluate end-of-season livestock disturbance should be accurate, repeatable, related to grazing intensity, representative of the cumulative effects of grazing within a season, and related to long-term stream conditions. When standards are applied to an indicator the overall accuracy of the measurement does not have as much merit as ensuring the other criteria is fulfilled. Kruskal (1991) argues that there are no true values, just different ways of measurement.

In this study I found that streambank alteration was related to other disturbance indicators, was moderately repeatable, and was related to grazing intensity. While the LI and Mod methods provided a more accurate snapshot of livestock disturbance, MIM and SLA had greater signal of the cumulative impacts from livestock throughout the grazing season. This is why the MIM protocol explained more of the long-term stream conditions than the Mod protocol. While many factors can affect the outcomes, MIM and SLA streambank alteration can be effective monitoring tools when used in conjunction with other indicators of livestock disturbance.

Stubble height at the end of the grazing season has been regarded as a dependable indicator of livestock use in riparian areas for a number of years (Heady 1949; Kauffman et al. 1983a; Bengeyfield and Svoboda 1998; Clary and Leininger 2000; USDI-BLM 1996; Bryant et al. 2006; Burton et al. 2011). I found stubble height was a moderately repeatable indicator, related to grazing intensity, representative of the cumulative effects of grazing throughout the season, and was informative of long-term stream conditions.

The findings of this study suggest stubble height is a dependable monitoring tool for evaluating livestock disturbance at the end of the grazing season.

Estimates of woody shrub utilization have been used as an indicator of livestock use in riparian areas for many years (Heady 1949; Bengeyfield and Svoboda 1998; USDI-BLM 1996; Bryant et al. 2006; Burton et al. 2011). There are a number of acceptable methods for evaluating this indicator (e.g., Bonham 1989, USDI-BLM 1996, Hall and Max 1999; Burton et al. 2011). The method for evaluating woody browse in this study was weakly related to other indicators of livestock disturbance, had high observer variability, and was not related to grazing intensity. The findings of this research are likely a reflection of an inadequate design of woody browse methods and should not suggest that woody shrub utilization is poor indicator of livestock use. However, it does suggest that training for this method may be more time consuming than the other protocols.

In evaluating end-of-season conditions, it is important land manages monitor a suite of indicators of livestock disturbance because indicators may respond differently at different sites, under different vegetation types, and under different climatic patterns (Bryant et al. 2006, Burton et al. 2011). Managers should be cautious in taking action based on a single evaluation using any metric because there will always be some error in measure, regardless of the protocol used (Roper et al. 2002; Heitke et al. 2008, Roper et al. 2010). Since the greatest cost of monitoring livestock grazing are costs associated with getting to the site, streambank alteration, stubble height, and woody browse should all be measured once at the site (Burton et al. 2010). It is important that land managers use each of these short-term disturbance indicators as each can provided different information of the degree to which livestock grazing is influencing long-term riparian and stream health. Understanding the strengths and weakness of the indicators and the protocols used will aid with interpreting results and valuable resource for land managers implementing end-of-season disturbance monitoring in riparian areas.

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APPENDICES

Appendix A. Tables

Table 1. Mean and standard deviation (SD) climatic and landscape attributes for reaches in the study area including bankfull width, gradient, index of sinuosity, slope, percent forested, road density, precipitation, temperature, drainage density, and percent geology (sedimentary and igneous) which were considered as covariates within models of stream conditions.

Attribute	Mean	SD
Bankfull width (m) [a]	4.5	2.5
Gradient (%) [a]	2.1	1.5
Sinuosity [a]	1.3	0.2
Slope (%) [b]	25.1	12.9
Percent Forested (%) [b]	43.8	26.2
Road Density (km/km^2) [b]	2.9	2.7
Precipitation (m) [c]	0.7	0.3
Temperature (C°) [c]	4.9	1.7
Drainage Density (km/km^2) [c]	1.4	0.6
Sedimentary (%) [c]	10.3	21.9
Igneous (%) [c]	76.5	34.1

[a] Quantified at the reach scale.
[b] Quantified at the segment scale.
[c] Quantified at the catchment scale.

Table 2. Definitions of the types of disturbances used to define streambank alteration in all four protocols evaluated in this study. A streambank was altered when the presence of any of these three alterations were determined to have occurred in the current year (Heitke et al. 2008).

Types of alterations	Definition
Shearing	Removal of a portion of the streambank by hooves leaving a smooth vertical surface and an indentation of a hoof print at the bottom or along the sides.
Trampling	Indentation of a hoof print and exposed roots or soil, resulting in a depression at least 13 mm (1/2 in) deep or soil displacement at least 13 mm upwards.
Trailing	Trails/paths and other severe trampling are counted as alteration if there are signs of current year use. Because of compacted soils, trailing counts even if hoof prints do not result in a 13 mm depression.

Table 3. Descriptions of woody browse classes and associated midpoint values used for evaluations in 2011 (Burton et al. 2011).

Browse Class	Midpoint	Description
Unavailable	Blank	No shrub present or shrubs and trees have > 50% of current year growth > 1.5 m above the ground.
0%	0	No browse of woody vegetation.
1-20%	10	1-20% of current year leaders have been browsed leavening 80-99% of current year leaders intact.
21-40%	30	21-40% of current year leaders have been browsed leavening 60-79% of current year leaders intact.
41-60%	50	41-60% of current year leaders have been browsed leavening 40-59% of current year leaders intact.
61-80%	70	61-80% of current year leaders have been browsed leavening 20-39% of current year leaders intact.
81-100%	90	81-100% of current year leaders have been browsed leavening 0-19% of current year leaders intact.

Table 4. Overall mean and standard deviation (SD) of percent streambank alteration, stubble height (SH; *n* = 212) and woody browse (WB; *n* = 133) for all reach evaluations. Percent alteration was evaluated using four streambank alteration protocols: Multiple Indicator Monitoring (MIM; *n* = 212), Modified MIM (Mod; *n* = 212), Single Line Alteration (SLA; *n* = 30), and Line Intercept (LI; *n* = 27).

	MIM (%)	Mod (%)	SLA (%)	LI (%)	SH (cm)	WB (%)
Mean	23.6	8.8	26.3	10.4	24.2	23
SD	20.9	9.5	21.2	12.4	14.4	20.1

Table 5. Overall mean, root mean square error (RMSE), coefficient of variation (CV), and ratio of signal to noise (S:N) for repeat measurements of percent streambank alteration, stubble height (SH; n = 146) and woody browse (WB; n = 76). Percent alteration was evaluated using four streambank alteration protocols: Modified MIM (Mod; n = 146), Multiple Indicator Monitoring (MIM; n = 146), Single Line Alteration (SLA; n = 30), and Line Intercept (LI; n = 15).

	MIM (%)	Mod (%)	SLA (%)	LI (%)	SH (cm)	WB (%)
Reaches	72	72	30	15	72	38
Mean	22.7	8.2	26.3	5.6	24.9	22
RMSE	7	4.5	6.9	1.8	8.3	14.5
CV	30.6	54.3	26.4	32.3	33.2	65.9
S:N	8.4	3.3	8.8	15.2	2.7	1.3

Table 6. Annual mean and standard deviation (SD) of for multiple indicator monitoring (MIM) and Modified MIM (Mod) percent streambank alteration, stubble height (SH), and total water year precipitation for the 63 reaches that were evaluated during both years of the study.

	MIM (%)		Mod (%)		SH (cm)		Precip (cm)	
	2010	2011	2010	2011	2010	2011	2010	2011
Mean	35.4	20.9	15.0	7.0	26.2	23.8	62.8	74.4
SD	25.4	17.5	12.7	6.3	16.6	13.7	23.6	32.3

Table 7. Parameter estimates, model structure, and model fit (adjusted R^2) for multiple linear regression models for multiple indicator monitoring (MIM) and Modified MIM (Mod) streambank alteration and stubble height. Covariates include: bankfull width (m), gradient (%), and sinuosity of the reach; average annual precipitation (precip; m) and temperature (temp; C°), and percent igneous geology of the catchment.

Indicator	Regression Model	Adjusted R^2
MIM (%)	50.9 – 2.7(bankfull) + 4.6(drainage) – 10.4(precip) – 2.1(temp) – 1.8(gradient)	0.14
Mod (%)	17.9 – 0.86(bankfull) + 2.7(drainage) – 5.2(precip) – 1.0(temp)	0.10
SH (cm)	2.5 + 13.1(sinuosity) – 0.08(igneous) + 12.3(precip) + 0.94(temp) – 1.5(gradient)	0.14

Table 8. Parameter estimates, model structure, model fit (R^2), Akaike information criterion (AIC), value for the multiple linear regression models for stream habitat variables. Covariates include: bankfull width (bf; m), gradient (%), and sinuosity (sin) or the reach; slope (%), forested cover (%) of the segment; road density (road; km/km^2), average annual precipitation (precip; m) and temperature (temp; C$^{\circ}$), and percent sedimentary(sed) and igneous (ign) geology of the catchment; multiple indicator monitoring (MIM; %) and Modified MIM (Mod; %) streambank alteration and stubble height.

Stream Attribute	Regression Model	Indicator *P*-Value	Adjusted R^2	AIC	Δ AIC
Width to depth ratio	2.95 + 2.9(bf) + 1.0(grad) + 0.12(slope) + 1.7(drainage) – 9.7(precip)		0.52	796	
	-0.22 + 3.1(bf) + 1.1(grad) + 0.13(slope) + 1.4(drainage) – 9.0(precip) + 0.08(MIM) **	0.002	0.54	787	-8.37
	0.78 + 3.0(bf) + 1.1(grad) + 0.12(slope) + 1.4(drainage) – 9.0(precip) + 0.15(Mod) **	0.005	0.54	789	-6.14
	3.0 + 2.9(bf) + 0.9(grad) + 0.12(slope) + 1.7(drainage) – 9.0(precip) – 0.05(SH)	0.114	0.52	795	-0.60
Bank angle (°)	113 + 1.2(bf) – 18.1(sin) + 1.5(grad) + 0.22(slope) – 14.9(precip) + 3.1(temp) + 0.07(ign) + 0.15(sed)		0.35	1164	
	106 + 1.5(bf) – 17.2(sin) + 1.7(grad) + 0.23(slope) – 13.9(precip) + 3.3(temp) + 0.06(ign) + 0.14(sed) + 0.12(MIM) **	0.032	0.36	1161	-2.84
	110 + 1.4(bf) – 17.6(sin) + 1.6(grad) + 0.22(slope) – 14.3(precip) + 3.3(temp) + 0.06(ign) + 0.14(sed) + 0.16(Mod)	0.175	0.35	1164	0.06
	113 + 1.2(bf) – 15.6(sin) + 1.2(grad) + 0.22(slope) – 12.7(precip) + 3.3(temp) + 0.05(ign) + 0.16(sed) – 0.18(SH) **	0.028	0.36	1161	-3.07
Percent undercut banks	13.0 + 18.3(sin) – 0.27(slope) + 13.3(precip) – 2.3(temp) – 0.07(sed)		0.28	1147	
	16.7 + 18.9(sin) – 0.29(slope) + 11.5(precip) – 2.4(temp) – 0.07(sed) – 0.10(MIM) **	0.052	0.29	1145	-1.90
	15.3 + 18.5(sin) – 0.28(slope) + 12.2(precip) – 2.4(temp) – 0.06(sed) – 0.15(Mod)	0.179	0.28	1147	0.13
	14.8 + 15.8(sin) – 0.27(slope) + 10.6(precip) – 2.4(temp) – 0.08(sed) + 0.17(SH) **	0.028	0.29	1144	-3.02
Bank stability	110 – 0.42(bf) – 9.1(sin) – 0.02(ign)		0.06	856	
	110 – 0.41(bf) – 9.1(sin) – 0.02(ign) + 0.0007(MIM)	0.978	0.06	858	2.00
	111 – 0.44(bf) – 9.1(sin) – 0.02(ign) – 0.02(Mod)	0.717	0.06	858	1.86
	110 – 0.48(bf) – 10.7(sin) – 0.01(ign) + 0.09(SH) **	0.021	0.08	853	-3.43
Residual pool depth (m)	0.15 + 0.03(bf) – 0.05(grad) – 0.002(slope) – 0.001(forest) – 0.03(drainage) + 0.16(precip) + 0.02(temp) + 0.001(sed)		0.45	-774	
	0.18 + 0.03(bf) – 0.05(grad) – 0.002(slope) – 0.0008(forest) – 0.03(drainage) + 0.15(precip) + 0.02(temp) + 0.001(sed) – 0.0006(MIM)	0.309	0.45	-773	0.91
	0.17 + 0.03(bf) – 0.05(grad) – 0.002(slope) – 0.0008(forest) – 0.02(drainage) + 0.15(precip) + 0.02(temp) + 0.001(sed) – 0.001(Mod)	0.262	0.45	-773	0.67
	0.12 + 0.03(bf) – 0.04(grad) – 0.002(slope) – 0.0008(forest) – 0.03(drainage) + 0.12(precip) + 0.02(temp) + 0.001(sed) + 0.002(SH) **	0.002	0.47	-781	-7.74
Percent Pools	21.8 + 11.8(sin) – 7.4(grad) – 0.45(slope) – 0.11(forest) – 3.7(drainage) + 21.9(precip) + 2.4(temp) + 0.1(ign) + 0.11(sed)		0.41	1185	
	24.7 + 12.0(sin) – 7.4(grad) – 0.47(slope) – 0.11(forest) – 3.1(drainage) + 20.1(precip) + 2.3(temp) + 0.11(ign) + 0.12(sed) – 0.1(MIM)	0.131	0.42	1184	-0.42
	24.2 + 11.8(sin) – 7.4(grad) – 0.47(slope) – 0.11(forest) – 3.0(drainage) + 20.3(precip) + 2.3(temp) + 0.11(ign) + 0.12(sed) – 0.21(Mod)	0.134	0.42	1184	-0.38
	21.5 + 10.5(sin) – 7.2(grad) – 0.46(slope) – 0.11(forest) – 3.6(drainage) + 20.6(precip) + 2.3(temp) + 0.11(ign) + 0.11(sed) + 0.10(SH)	0.301	0.41	1186	0.87
Percent fine sediment < 6 mm	15.4 – 4.0(bf) + 23.5(sin) – 0.92(slope) – 1.5(road) + 15.0(precip) + 4.9(temp)		0.36	827	
	8.4 – 3.7(bf) + 23.2(sin) – 0.90(slope) – 1.6(road) + 16.6(precip) + 5.1(temp) + 0.15(MIM)	0.189	0.37	827	0.15
	8.7 – 3.7(bf) + 23.4(sin) – 0.90(slope) – 1.5(road) + 16.9(precip) + 5.1(temp) + 0.33(Mod)	0.182	0.37	827	0.09
	16.3 – 4.0(bf) + 21.7(sin) – 0.91(slope) – 1.4(road) + 13.7(precip) + 4.9(temp) + 0.10(SH)	0.569	0.36	829	1.65
D_{50} (m)	0.07 + 0.003(bf) – 0.03(sin) + 0.0005(slope) + 0.0002(forest) – 0.02(precip) – 0.005(temp) – 0.0001(ign) – 0.0002(sed)		0.39	-1050	
	0.08 + 0.003(bf) – 0.02(sin) + 0.0005(slope) + 0.0002(forest) – 0.02(precip) – 0.005(temp) – 0.0001(ign) – 0.0002(sed) – 0.0001(MIM)	0.152	0.39	-1051	-0.22
	0.08 + 0.003(bf) – 0.03(sin) + 0.0005(slope) + 0.0002(forest) – 0.02(precip) – 0.005(temp) – 0.0001(ign) – 0.0002(sed) – 0.0003(Mod)	0.170	0.39	-1050	-0.05
	0.07 + 0.003(bf) – 0.02(sin) + 0.0005(slope) + 0.0002(forest) – 0.02(precip) – 0.005(temp) – 0.0001(ign) – 0.0002(sed) – 0.0001(SH)	0.455	0.38	-1049	1.39

** Indicates the added disturbance indicator was significant, improved model fit, and had a lower AIC value.

Appendix B. Figures

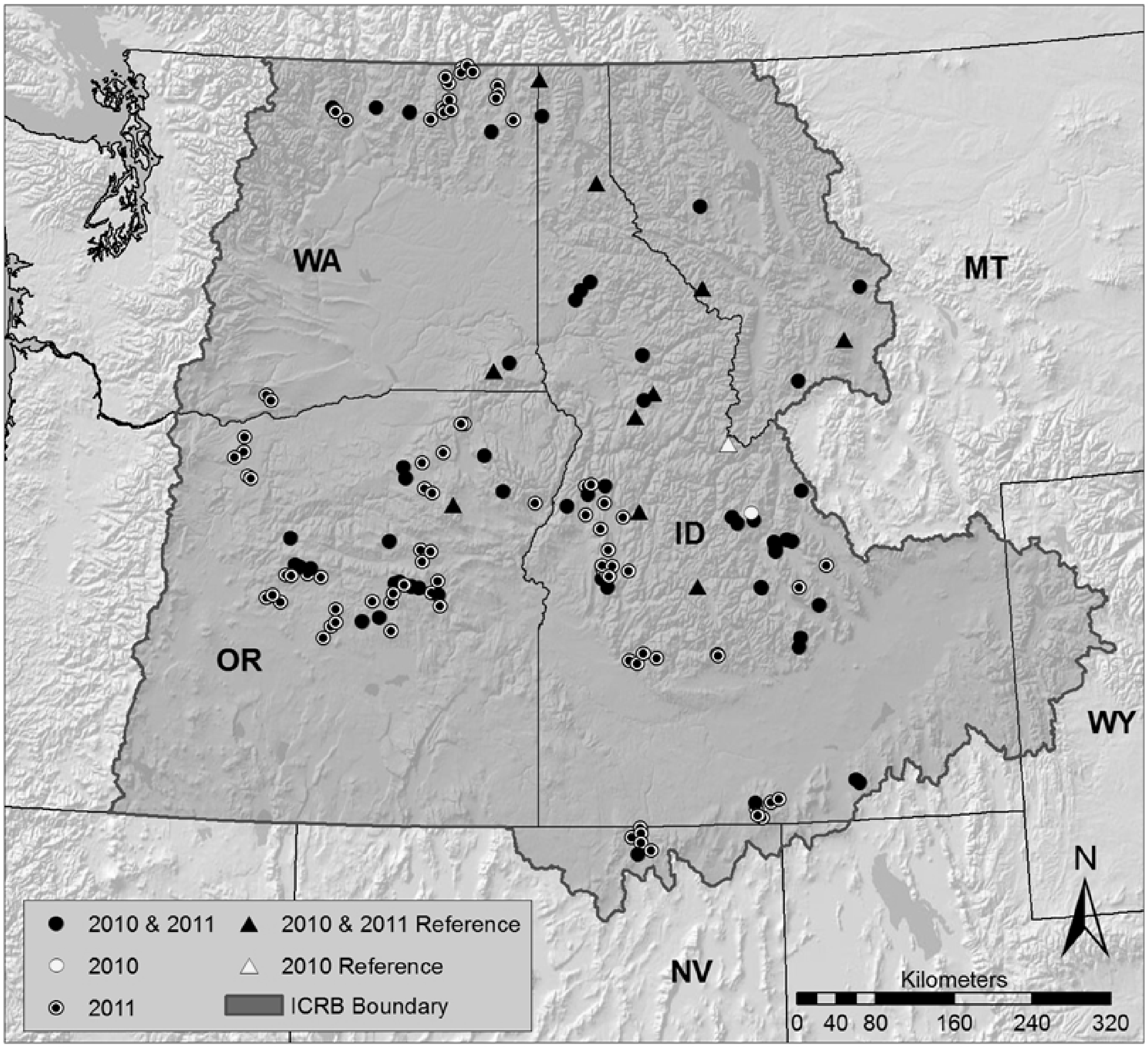

Figure 1. Map of Interior Columbia River Basin (IRCB) study area, displaying the distribution of referenced (triangles) and grazed (circle) reaches by year: evaluated in both 2010 and 2011 (filled symbol), evaluated in 2010 (hollow symbol), and evaluated in 2011 (circle with a dot).

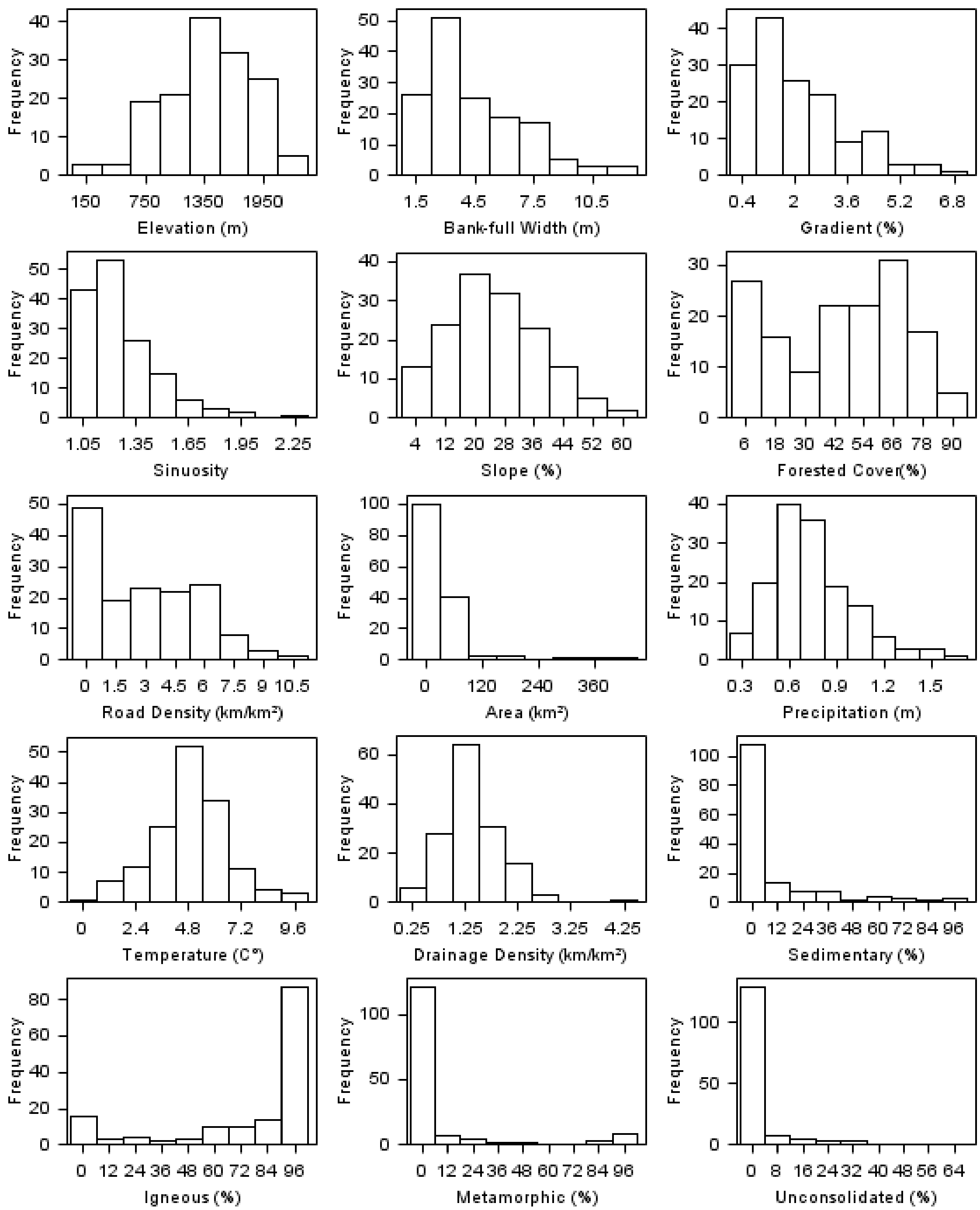

Figure 2. Frequency and distribution of geo-climatic attributes for evaluated sites in the study area including elevation. bankfull width, gradient, and index of sinuosity of the evaluated reaches; percent slope, percent forested, road density of the segments; and area, precipitation, temperature, drainage density, and percent geology (sedimentary, igneous, metamorphic, unconsolidated) of the upstream watershed catchments.

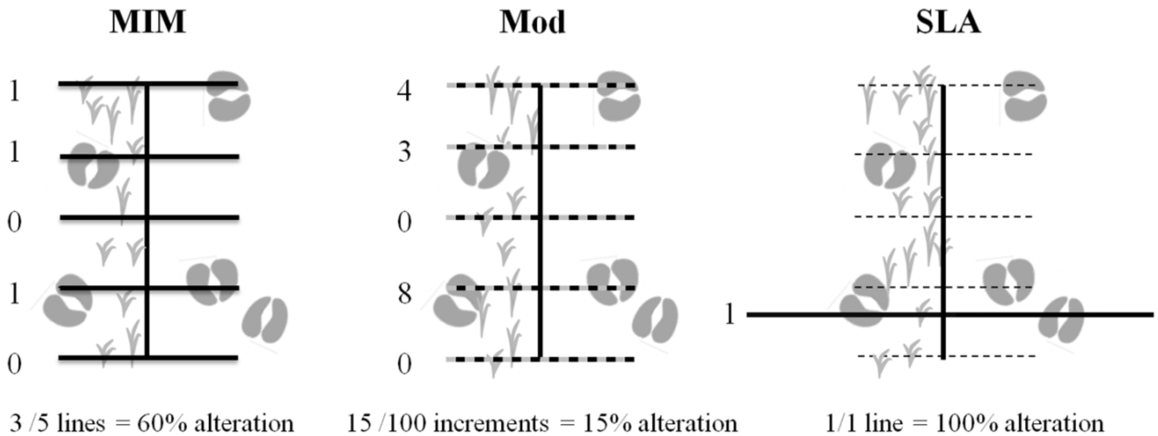

Figure 3. Monitoring quadrat frames for three rapid assessment protocols for evaluating streambank alteration: Modified MIM (Mod, left), Multiple Indicator Monitoring (MIM, center), Single Line Alteration (SLA, right). The amount of streambank alteration varies depending on the method and quadrat frame used.

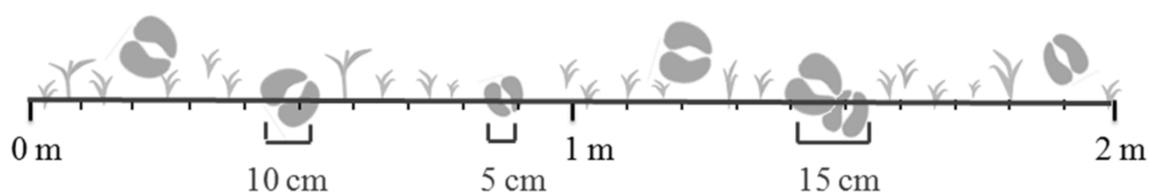

Figure 4. Line intercept method for evaluating streambank alteration. Diagram of a 2 m portion of the streambank: the length of alteration that is located directly below the measuring tape is 30 cm.

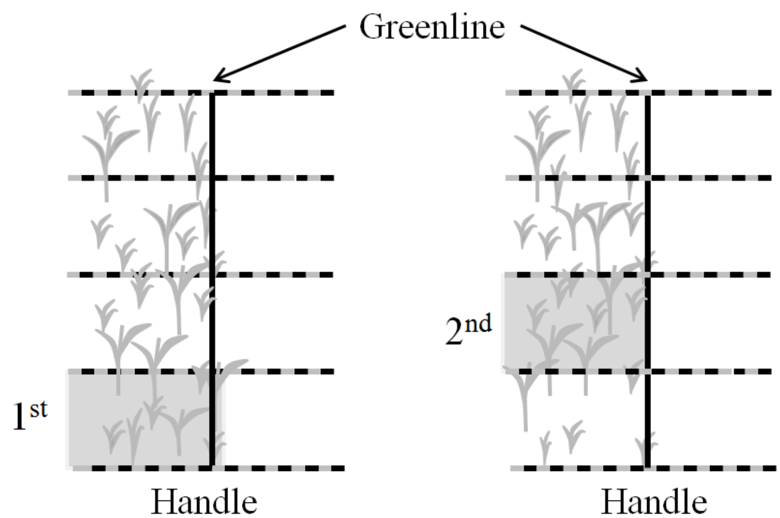

Figure 5. Median stubble height was recorded for herbaceous vegetation composing at least 25% cover in the first 10 x 20 cm section of the quadrat frame closest to the handle (left); if vegetation didn't cover 25% of the first subplot, the observer then recorded the median height of vegetation in the nearest 10 x 20 cm subplot on the greenline side of the quadrat frame that did have 25% cover (right).

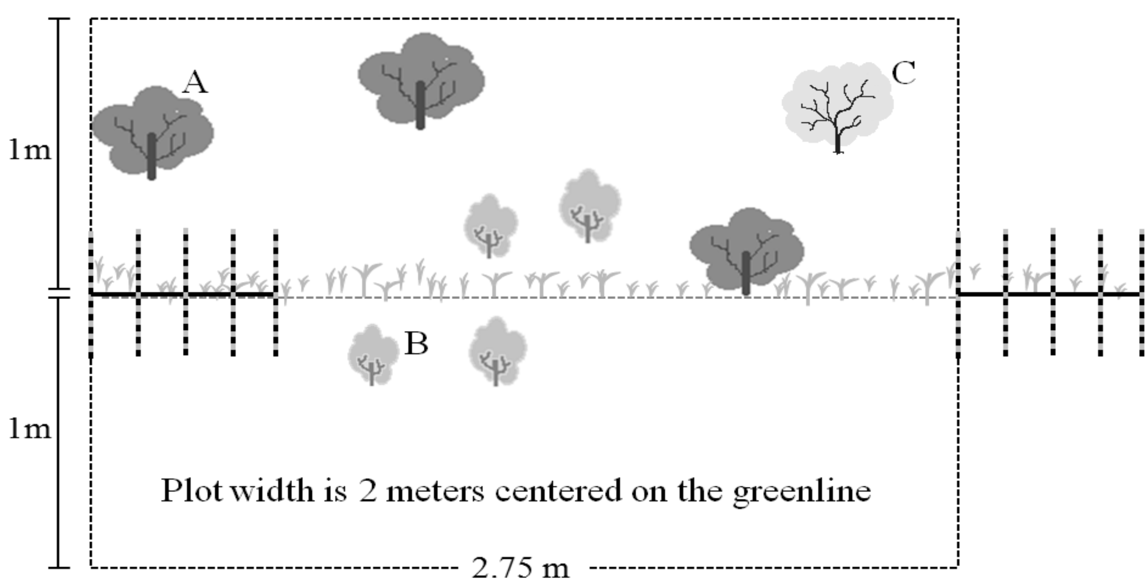

Figure 6. Aerial view of the plot area for woody browse evaluations. Woody Browse was recorded within a 2 m wide plot centered on the greenline extending 2.75 m from the quadrat handle to the next consecutive quadrat handle. Percent browse was record for the first woody plant nearest the quadrat handle for each of the shrub types. In this diagram percent woody browse would be evaluated on shrub A, B, and C (Burton et al. 2011).

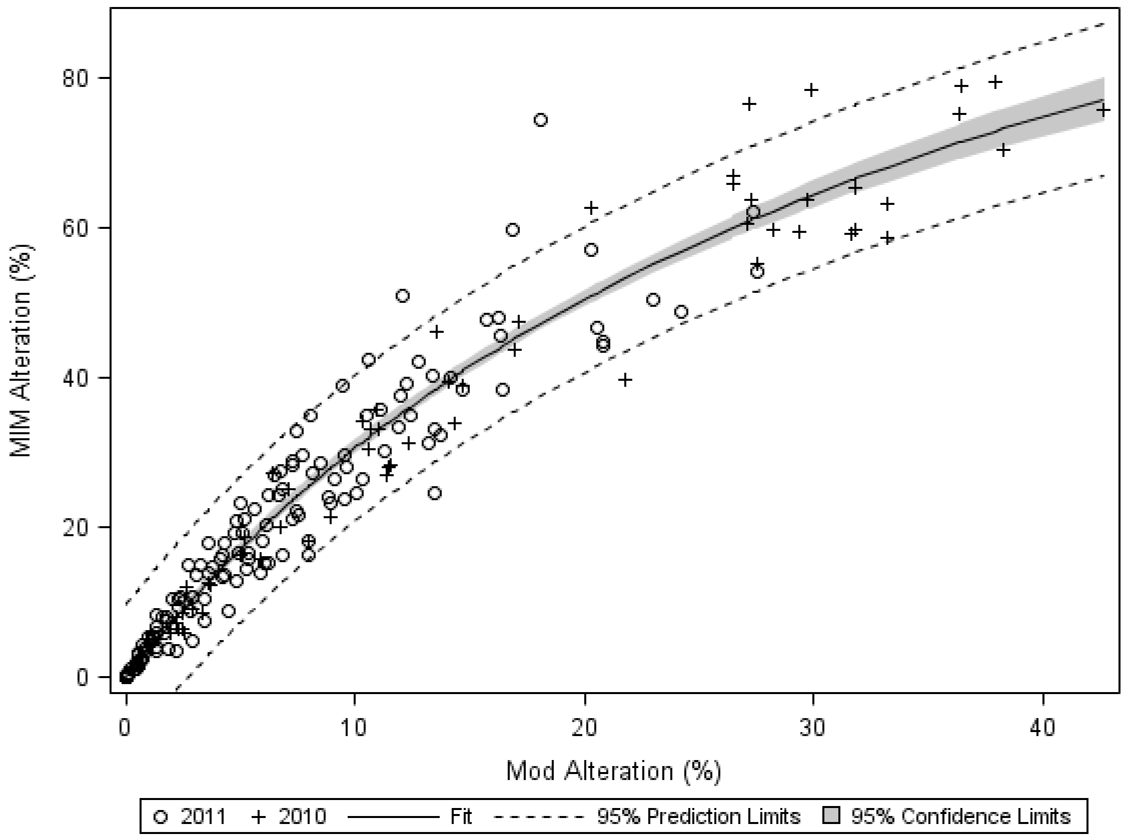

Figure 7. The nonlinear relation between the Multiple Indicator Monitoring (MIM, dependant variable) and the Modified MIM (Mod, independent variable) method for evaluating streambank alteration.

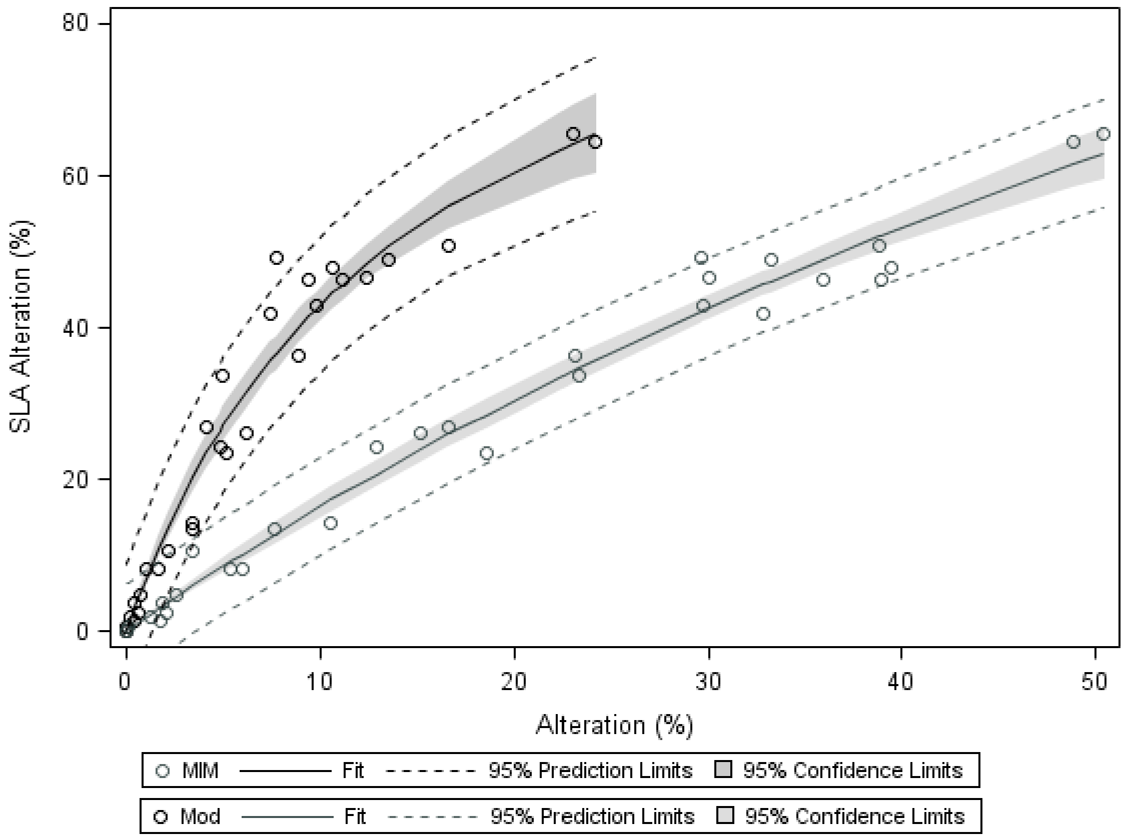

Figure 8. The nonlinear relation between the Single Line Alteration method (SLA, dependant variable) with Multiple Indicator Monitoring (MIM, grey, independent variable) and the Modified MIM (black, independent variable) methods for evaluating streambank alteration.

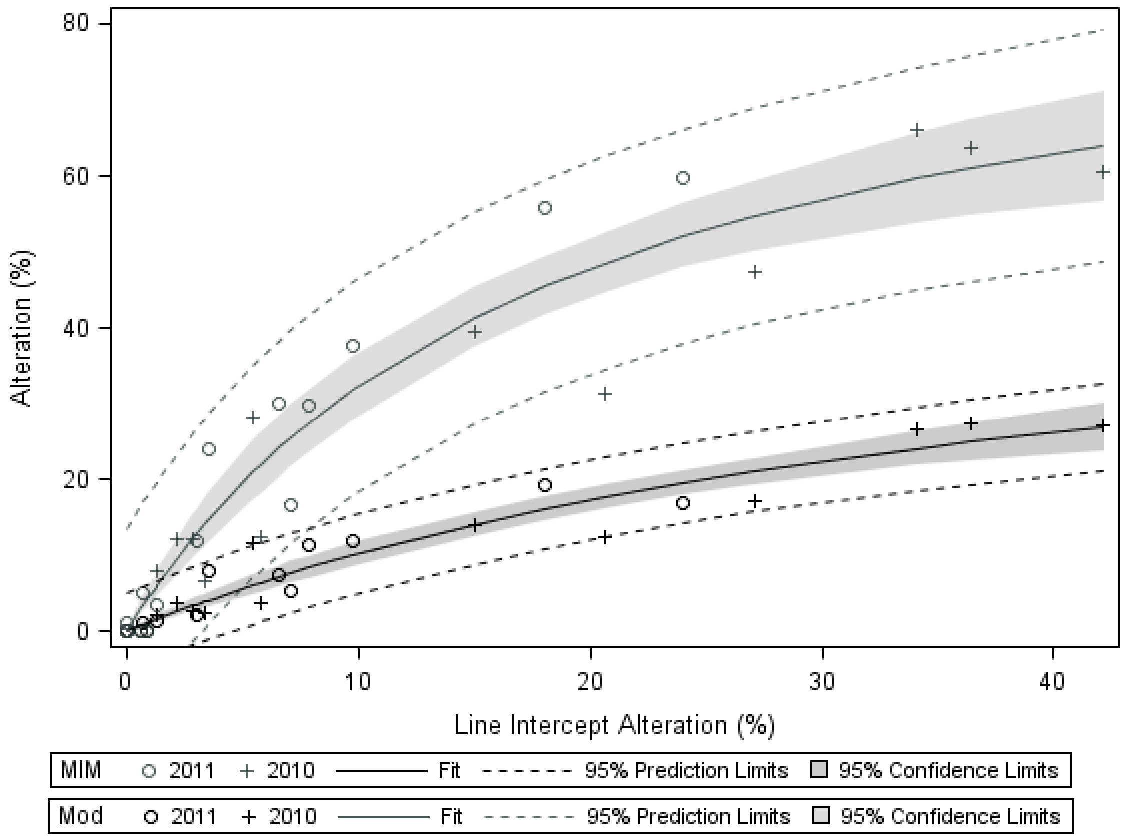

Figure 9. The nonlinear relations between the Line Intercept method (independent variable) with Multiple Indicator Monitoring (MIM, grey, dependent variable) and the Modified MIM (black, dependent variable) methods for evaluating streambank alteration.

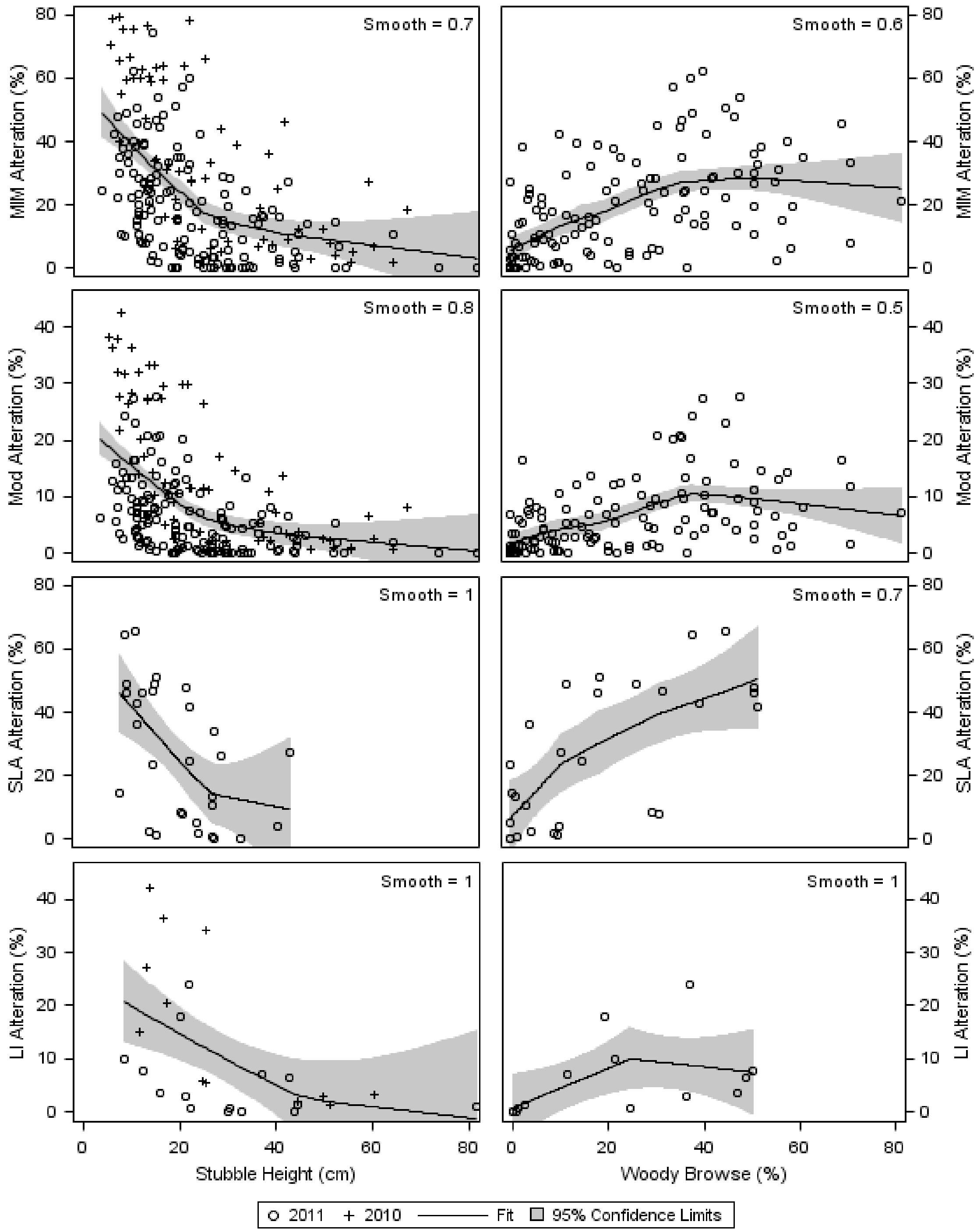

Figure 10. Locally weighted regression (LOESS) relations among stubble height, woody browse (independent variables) and four streambank alteration protocols (dependent variables): Multiple Indicator Monitoring (MIM), Modified MIM (Mod), Single Line Alteration (SLA), and Line Intercept (LI).

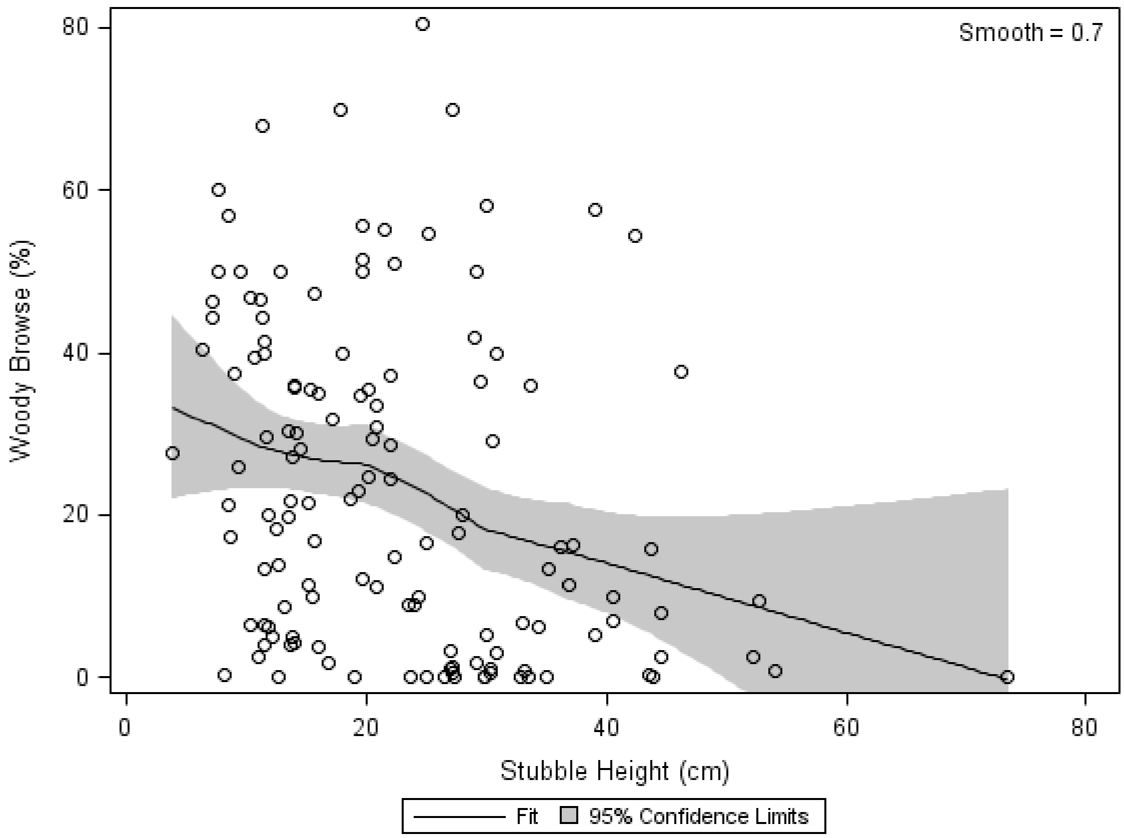

Figure 11. Locally weighted regression (LOESS) relation between stubble height (independent variable) and woody browse (dependent variable).

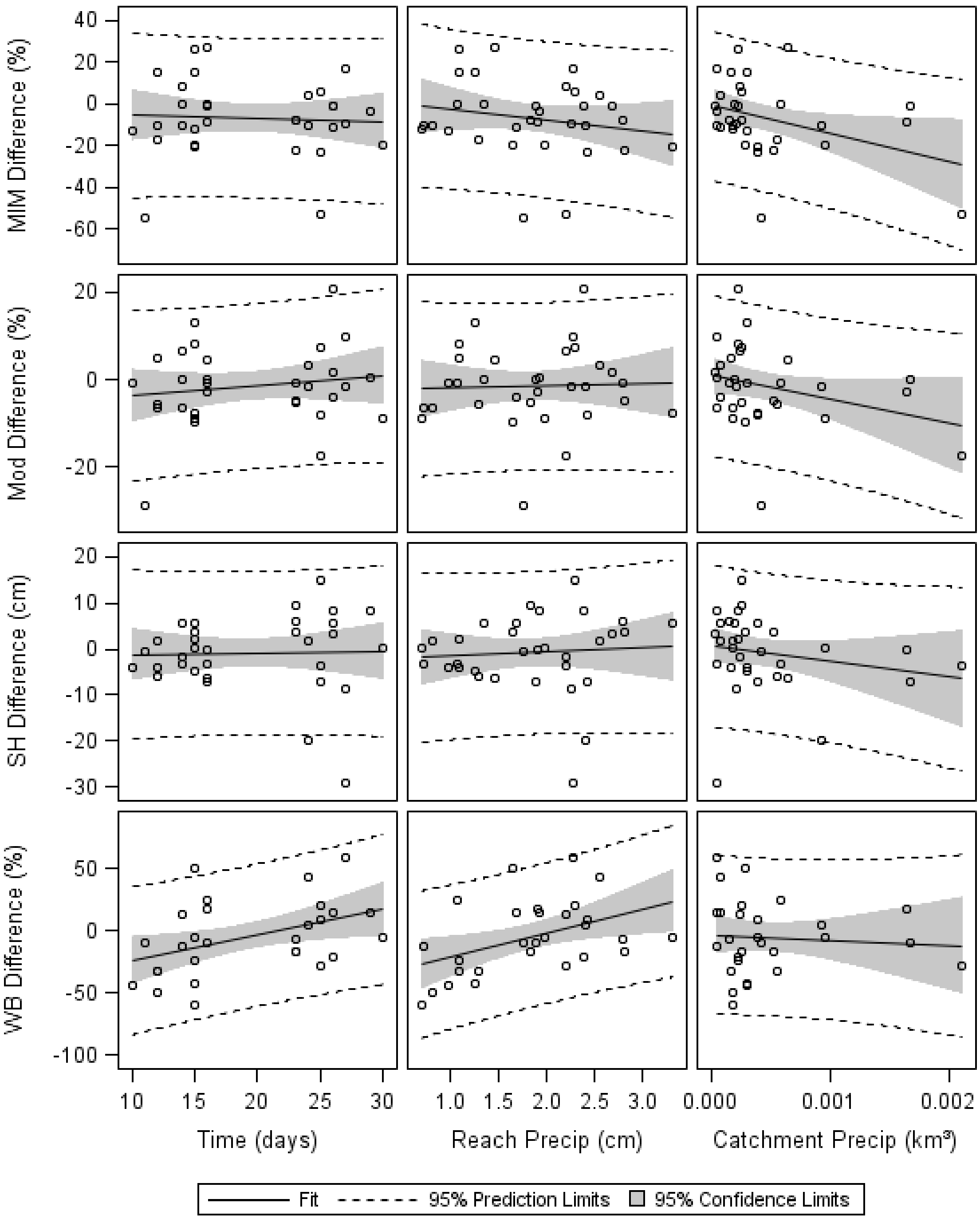

Figure 12. The linear relationships of changes to livestock disturbance indicators with three end-of-season variables: time, total precipitation (precip) at the reach, and volume of precipitation to the watershed catchment (dependent variable) among changes (difference). Disturbance indicators (independent variables) include: streambank alteration Multiple Indicator Monitoring (MIM; *n* = 34) and Modified MIM (Mod; *n* = 34), stubble height (SH; *n* = 34), and woody browse (WB; *n* = 27).

Figure 13. Repeat photographs of providing evidence that livestock grazing livestock grazing continued after the first evaluation. Photographs Silver Creek, Boise National Forest, ID taken on 16 September 2011 (top) and 13 October 2011 (bottom).

Figure 14. Repeat photographs of providing evidence of increased stage height between two end-of-season evaluations. Photographs of Willow Creek, Boise National Forest, ID taken on 17 September 2011 (top) and 12 October 2011 (bottom).

Figure 15. Repeat photographs of providing evidence of effects of time (seasonality) and precipitation resulting in alteration that was less evident at the second evaluation. Photographs of Crooked Creek, Payette National Forest, ID taken on 15 September 2011 (top) and 15 October 2011 (bottom).

Figure 16. Repeat photographs of Crooked Creek, Payette National Forest, ID providing evidence of erosion to displaced and disturbed soils along the streambank. Top photograph depicts current year disturbance including hoofprints, shears, and displaced soils (15 September 2011). Bottom photograph depicts erosion to the disturbed streambanks with hoofprints, shears, and displaced soils being absent or difficult to identify as current year (15 October 2011).

Figure 17. Repeat photographs of providing evidence that hoofprint alterations were less defined at the time of the second evaluation. Photographs of Pine Creek, Boise National Forest, ID taken on 18 September 2011 (top) and 13 October 2011 (bottom).

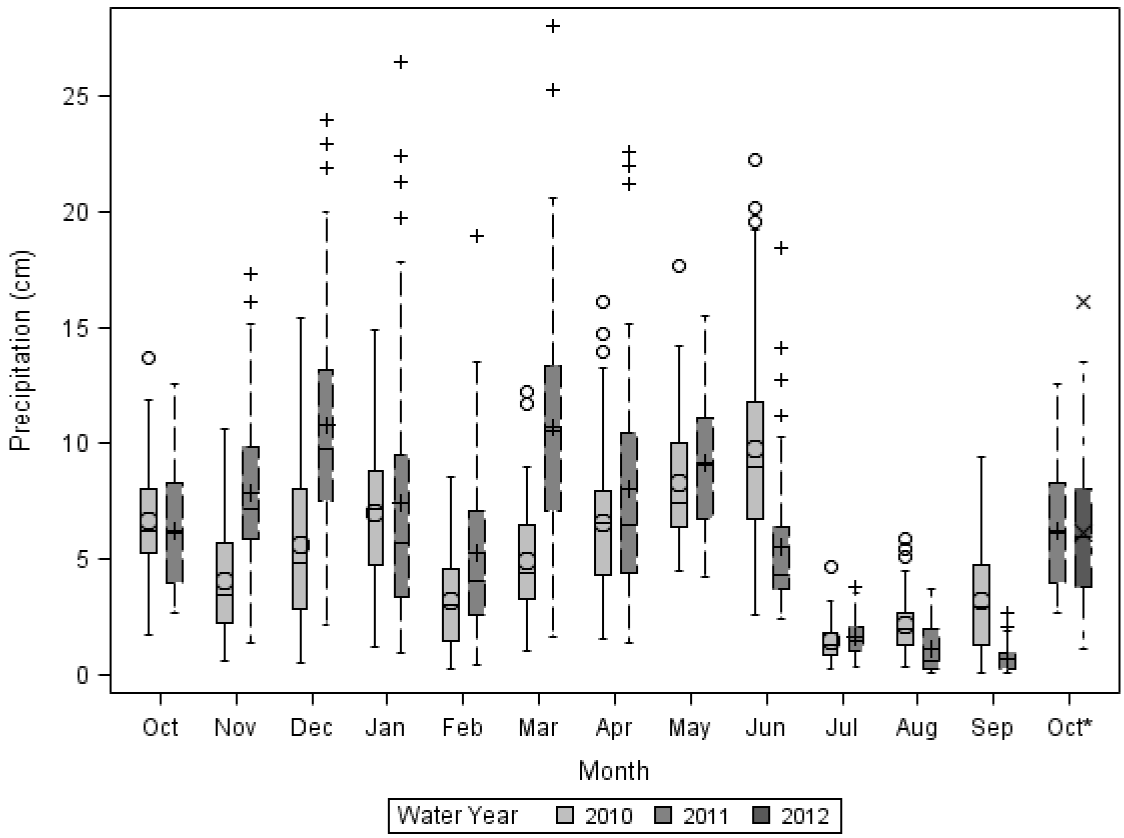

Figure 18. Monthly distribution of precipitation by water year for the 63 reaches that were evaluated in 2010 and 2011. October (Oct*) is not include in the water year but was included in the graph.

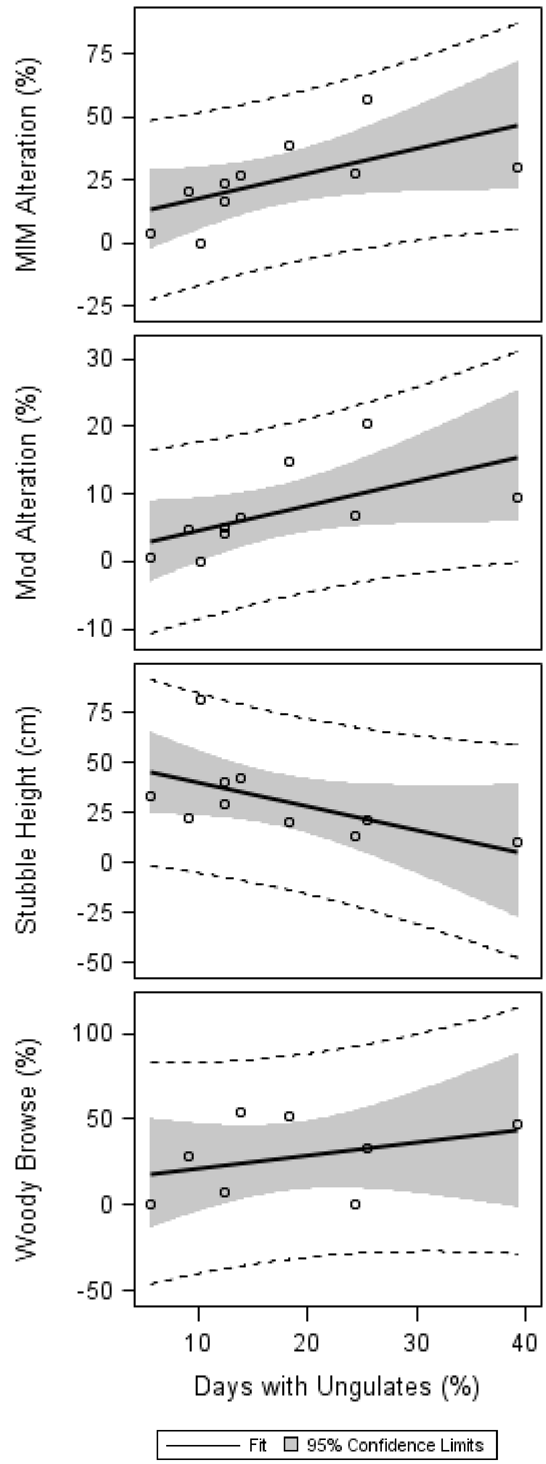

Figure 19. The linear relations between livestock disturbance indicators and grazing intensity (percent of days with ungulates within the riparian area, dependent variable). Disturbance indicators (independent variables) include: streambank alteration Multiple Indicator Monitoring (MIM; n = 10) and Modified MIM (Mod; n = 10), stubble height (n = 10), and woody browse (n = 9).